The Society of Automotive Engineers Clean Snowmobile Challenge 2001

FINAL REPORT

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Institute of
Science,
Ecology, and the
Environment

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EXECUTIVE SUMMARY

In response to increasing concern about snowmobile noise and air pollution, Teton County Wyoming Commissioner Bill Paddleford and environmental engineer Dr. Lori Fussell worked with The Society of Automotive Engineers (SAE) and the Institute of Science, Ecology, and the Environment (ISEE) to organize an intercollegiate design competition, the SAE Clean Snowmobile Challenge (SAE CSC).

The goal of the SAE CSC was to encourage development of a snowmobile with improved emission and noise characteristics that does not sacrifice performance. Modifications were expected to be cost effective and practical.

The second year of the competition, the SAE CSC2001, was held in Jackson Hole, Wyoming from March 24 – 30, 2001. Major sponsors of the SAE CSC2001 included the United States Environmental Protection Agency, Flagg Ranch Resort, Montana Department of Environmental Quality, Wyoming Department of Environmental Quality, International Snowmobile Manufacturers Association, Teton County Wyoming, Peaks to Prairies Pollution Prevention Information Center, United States Department of Energy, and WestStart.

Those participating in the event competed against each other in the categories of emissions, fuel economy/range, noise, acceleration, handling, cold-start, hill climb, engineering design paper, oral presentation, cost minimization, and static display. Points were awarded to teams based on their performance in each of the events.

The University of Waterloo won the SAE CSC2001 with a snowmobile featuring a two-stroke engine with catalytic aftertreatment and a custom silencer. This first-place entry was successful at reducing noise and emissions while simultaneously improving fuel economy and maintaining adequate performance. It was a reliable entry, successfully completing and passing all competition events.

1. INTRODUCTION

Snowmobiles provide hours of exhilarating winter fun for many outdoor enthusiasts, but these fun machines also present an ongoing environmental challenge in the form of excessive exhaust emissions and high noise levels. In an effort to find solutions to the emission and noise challenges presented by snowmobiles, Teton County Wyoming Commissioner Bill Paddleford and environmental engineer Dr. Lori Fussell worked with the SAE to form a new intercollegiate design competition, the Clean Snowmobile Challenge (SAE CSC).

By bringing this new competition to engineering students in both the United States and Canada, SAE CSC organizers brought new energy, ideas, and enthusiasm to a much needed environmental/automotive engineering design problem. Students are quickly committed to making their designs succeed and often attempt unique solutions to problems, bringing new perspectives to existing engineering challenges.

Much of the effort behind the formation and organization of the SAE CSC came from within the community of Jackson Hole, Wyoming. A Jackson Hole-based Advisory Board made up of local land managers, businessmen, snowmobilers, and environmentalists assisted the SAE, Commissioner Paddleford, and Dr. Fussell with the development of the competition.

The first SAE CSC (SAE CSC2000) was held in March of 2000. Seven teams from Canada and the United States competed in the first event. A few teams at the competition demonstrated large reductions in snowmobile noise and emissions. However, the majority of the participants suffered from a lack of development time and did not pass the emission and noise tests. (1-7)

The second SAE CSC (SAE CSC2001) was organized jointly by the Society of Automotive Engineers and the Institute of Science, Ecology, and the Environment. It was held in Jackson Hole, Wyoming at the end of March 2001. This paper summarizes the results of the competition.

Major sponsors of the SAE CSC2001 included the United States Environmental Protection Agency, Flagg Ranch Resort, Montana Department of Environmental Quality, Wyoming Department of Environmental Quality, International Snowmobile Manufacturers Association, Teton County Wyoming, Peaks to Prairies Pollution Prevention Information Center, United States Department of Energy, and WestStart. A complete list of competition sponsors is located in Section 6 of this report.

The goals of the SAE CSC2001 were:

- To give a hands-on, team-oriented, engineering design experience to university students.
- To encourage the research and development of advanced snowmobile technology.
- To give snowmobilers, outfitters, land managers, government officials, and those concerned about the environment the opportunity to work together to help find solutions that will decrease the impact of snowmobiles on the environment.
- To provide positive publicity opportunities for SAE CSC2001 sponsors and the community surrounding Jackson Hole and Teton County Wyoming.

2. COMPETITION OVERVIEW

2.1. Object of Competition

The object of the SAE CSC2001 was to develop a snowmobile that is acceptable for use in environmentally sensitive areas. The modified snowmobiles were expected to be quiet, emit significantly less unburned hydrocarbons (UHC) and carbon monoxide (CO) than conventional snowmobiles (without significantly increasing oxides of nitrogen emissions), and maintain or improve the performance characteristics of conventional snowmobiles. The modified snowmobiles were also expected to be cost-effective.

Although the modified snowmobiles competed in several performance events, the intent of the competition was to design a touring snowmobile that would primarily be ridden on groomed snowmobile trails. The use of unreliable, expensive solutions was strongly discouraged.

2.2. General Rules

Once selected for participation in the SAE CSC2001, student competitors had just seven months to make modifications to a snowmobile of their choice. Modifications were permitted to the snowmobile's engine, suspension, fuel management system, drivetrain, track, skis, and body. Major modification restrictions included:

- Two-stroke and rotary engines were limited to a displacement of 600 cc, and four-stroke engines were limited to a displacement of 960 cc.
- The snowmobile's chassis and track had to be commercially available.
- Fuel choice was limited to premium gasoline, a blend of 90% gasoline (either premium or regular) and 10% ethanol, or electricity.
- Fuel additives (with the exception of commercial two-stroke oil) were not permitted.
- The snowmobile had to remain track driven and ski steered.
- The snowmobile had to be propelled with a variable ratio belt transmission.

- Traction control devices were not allowed.

A complete listing of competition rules and restrictions is available in *The SAE Clean Snowmobile Challenge 2001 Rules* (8), located in Appendix A of this report.

2.3. Competition Events and Scoring

Student teams in the SAE CSC2001 competed in seven dynamic events and three static events. Dynamic events included emissions, fuel economy/range, noise, acceleration, handling, cold-start, and hill climb. Static events included engineering design paper, oral presentation, and static display.

A breakdown of the points that were available for each event is located in Table 1.

Table 1 *CSC2001 Events and Available Points*

Event	Points Awarded for Passing Event	Additional Points Available for Relative Performance in Event
Emissions	200	250
Fuel Economy Range	100	100
Noise	100	150
Acceleration	Not Applicable	100
Handling	Not Applicable	50
Cold Start	100	Not Applicable
Hill Climb	Not Applicable	100
Engineering Design Paper	Not Applicable	100
Oral Presentation	Not Applicable	100
Static Display	Not Applicable	50
Total Points	**500**	**1000**

3. COMPETITION ENTRIES

3.1. Participating Universities

All collegiate chapters of the SAE were invited to submit a proposal to compete in the SAE CSC2001. Fourteen universities from the United States and Canada were selected to participate. The selected universities were:

- Clarkson University
- Colorado School of Mines
- Colorado State University
- Kettering University
- Michigan Technological University
- Minnesota State University, Mankato
- University at Buffalo, State University of New York
- University of Alaska, Fairbanks
- University of Alberta
- University of Idaho
- University of Kansas
- University of Waterloo
- University of Wyoming
- Western Washington University

Of the fourteen selected universities, all but two were able to compete in SAE CSC2001 events. Western Washington University did not attend the competition and Colorado State University experienced an engine failure during pre-event emission testing. Colorado State University went on to compete only in the static events.

3.2. Technical Description of Entries

Essentially, four distinct approaches to meeting competition objectives were used by SAE CSC2001 participants. They were:

1. Use of a conventional two-stroke snowmobile engine with modified fuel management and the addition of exhaust aftertreatment.

2. Use of a supercharged two-stroke snowmobile engine retrofitted to a reverse uniflow design with catalytic aftertreatment.
3. Use of a four-stroke motorcycle engine without exhaust aftertreatment.
4. Use of a four-stroke engine (automotive, motorcycle, and all terrain vehicle engines were all used) featuring electronic fuel injection and the addition of exhaust aftertreatment. Some of these teams also chose to turbocharge their designs.

Teams also considered other strategies for the SAE CSC2001, including direct injection two-stroke engines and rotary engines. However, due to limited development time and other unexpected obstacles, none of the schools interested in direct injection or rotary engines were able to implement these designs in time for the competition.

Detailed information on seven of the teams' design strategies, challenges faced, and final results are available in the individual SAE CSC2001 participants' engineering design papers (9-15). A summary of all SAE CSC2001 snowmobiles is included in Table 2.

Table 2 *Summary of SAE CSC2001 Modification Strategies*

Participant	Base Chassis	Base Engine	Engine Cycle	Engine Mgmt	Fuel Delivery	Fuel	Emission Control Strategy	Noise Control Strategy
Clarkson University	Arctic Cat	Honda CBRT 929RR 929cc (Motorcycle)	4-stroke	Stock	Electronic Fuel Injection (EFI)	Premium Gasoline (PG)	Catalyst	Insulated engine compartment, Header wrap, Muffler
Colorado School of Mines	1998 Polaris Indy Trail	Honda CBR600 F-4 (Motorcycle)	4-stroke	Stock	Carburetors	Premium 10% ethanol blend (PE10)	Closed loop operation with three way catalyst (TWC)	Muffler, Insulation under cowling
Colorado State University	2000 Polaris RMK 600	Supercharged 600cc Polaris (Snowmobile)	2-stroke	Motec	EFI	PE10	Reverse uniflow two-stroke design, Lean operation with an oxidation catalyst (OXC)	Acoustic tuning for 8000 rpm with sound diffuser
Kettering University	Yamaha V-max	Turbocharged 659cc Daihatsu (Automobile)	4-stroke	Stock	EFI	PE10	Closed loop operation with TWC and exhaust gas recirculation (EGR)	Large volume intake and exhaust silencer, Dampened body panels
Michigan Technological University	1994 Yamaha Vmax 600	Honda VFR 781cc (Motorcycle)	4-stroke	Stock	EFI	PE10	Rich operation with TWC and secondary air injection, Electronic Control Module features barometric pressure and ambient temperature inputs	Barrier, damping, and absorbing materials
Minnesota State University, Mankato	2001 Polaris Edge	Polaris 500 cc (Snowmobile)	2-stroke	Motec M48	Carburetors	PE10	Lean operation with TWC	Single pipe, stock airbox, stock silencer with addition of catalyst, sound absorption materials
University at Buffalo, State University of New York	1998 Polaris Indy Trail	Turbocharged Polaris Sportsman 500cc (All Terrain Vehicle)	4-stroke	Magneti Marelli	EFI	PG	Closed loop operation with TWC and OXC	Student designed exhaust silencer, Foam
University of Alaska, Fairbanks	1998 Arctic Cat Powder Extreme	Turbocharged Suzuki 954 cc (Automobile)	4-stroke	Nippendens o/Bosch	EFI	PG	Closed loop operation with TWC and EGR, Positive crankcase ventilation	Reactive/absorption type muffler, Exhaust insulation
University of Alberta	1998 Polaris XCR	Suzuki GSXR 600cc (Motorcycle)	4-stroke	Wolf	EFI	PG	Closed loop operation with TWC	Absorbent liners, 2 expansion chambers, 4:1 exhaust manifold
University of Idaho	2001 Arctic Cat SnoPro	BMW K75RT 750cc (Motorcycle)	4-stroke	Open loop ECU	EFI	Regular 10% ethanol blend (E10)	Open loop operation with TWC	Under-hood sound damping
University of Kansas	Arctic Cat Powder Extreme	Honda CBZ 929RR 929cc (Motorcycle)	4-stroke	Stock	EFI	E10	Closed loop operation with TWC, Crankcase emission control	Stock muffler, Sound absorbing material
University of Waterloo	1998 Polaris Indy Trail	Polaris 520cc (Snowmobile)	2-stroke	Mechanical	Carburetors	PE10	Dual bed TWC with secondary air injection	Insulation, High volume silencer
University of Wyoming	1994 Polaris XLT	Kawasaki 617cc (Small Utility Vehicle)	4-stroke	Mechanical	Carburetors	PE10	4-stroke engine selection, no catalyst	Muffler

4. EVENT DESCRIPTIONS AND RESULTS

4.1. Emission Test

Emission testing at the SAE CSC2001 was the first-ever, dynamometer-based test of snowmobile emissions at high altitude (6800 feet) and ambient temperatures (25-35°F). A detailed report of the SAE CSC2001 emission testing procedure and results, prepared by Jeff White of the Southwest Research Institute, is contained in Appendix B of this report. A brief summary is contained below.

A mobile laboratory (truck) was outfitted with laboratory-grade instrumentation for measurement of 2-stroke and 4-stroke engine hydrocarbons (HC), carbon monoxide (CO), carbon dioxide (CO_2), oxides of nitrogen (NO_X), and oxygen (O_2) using raw exhaust gas sampling. Major equipment used in the mobile laboratory emissions bench included:

- 2-stroke HC, flame ionization detector (HFID) (Southwest Research Institute Design)
- 4-stroke HC, HFID (Rosemount 402)
- High CO, non-dispersive infrared analyzer (NDIR) (Horiba)
- Low CO, NDIR (Rosemount 868)
- CO_2, NDIR (Rosemount 868)
- NO_X, chemiluminescent analyzer (Rosemount 955)
- O_2 (Rosemount CM1EA)
- Raw exhaust sampling system with heated (375°F) sample lines
- Chart recorder
- Calibration gases, NIST traceable

To facilitate a comparison of SAE CSC2001 emission data with previously generated laboratory data, organizers planned to use the five-mode snowmobile test cycle, as developed by Southwest Research Institute (SwRI) for the International Snowmobile Manufacturers Association (ISMA) (17). However, one mode of this test, Mode 4, was problematic due to the low applied load and variability in snowmobile clutch engagement. Therefore, the ISMA 5-mode test cycle was modified, by eliminating Mode 4, and proportionally reassigning its mode weight to the remaining modes. The modified four-mode cycle used in the SAE CSC2001 is shown in Table 3.

Table 3 *SAE CSC2001 Four-Mode Test Cycle*

Mode	**1**	**2**	**3**	**4**
Speed, %	100	85	75	Idle
Torque, %	100	51	33	0
Wt. Factor, %	18	39	36	7

In the test cycle, test modes are run in order, from highest to lowest speed. One hundred percent engine speed is defined as the maximum steady engine speed in snowmobile operation. Torque values are specified as a percent of the maximum (wide-open throttle) torque observed at 100 percent speed in Mode 1.

A Dynojet snowmobile chassis dynamometer was used to load snowmobile engines during emission testing. Prior to testing, each snowmobile's stock suspension was removed and replaced with an adjustable dynamometer carriage that provided connection to the dynamometer from the rear belt sprocket, plus a means of adjusting belt tension.

Accurate fuel flow measurements were required to make brake-specific emissions measurements. Three different fuel flow measurement techniques were provided to accommodate the range of fuel supply systems.

Supplemental cooling was required during the testing. A supplemental cooling fan was used for fan cooled engines and an external heat exchanger system was used for liquid-cooled engines.

To pass the emission test, SAE CSC2001 participants were expected to reduce the CO emissions of their snowmobile by at least 25% and the $HC+NO_X$ emissions by at least 50%. Teams received 200 points for passing emissions, with another 250 points available to teams based upon their ability to simultaneously reduce emissions beyond competition minimums. Emission reductions were calculated based on the emissions of a 2001 Polaris Sport Touring snowmobile equipped with a 550 cc 2-stroke engine. Test results are summarized in Table 4.

Table 4 *SAE CSC2001 Emission Testing Results*

Participant	CO (g/kW-h)	CO % Reduction	$HC+NO_X$ (g/kW-h)	$UHC+NO_X$ % Reduction	Points Received
Clarkson University	736	52	19.2	89	378
Colorado School of Mines	948	38	34.4	81	328
Colorado State University	Not Tested				0
Kettering University	323	79	5.1	97	445
Michigan Technological University	Not Tested				0
Minnesota State University, Mankato	387	75	37.6	79	375
University at Buffalo, SUNY	267	82	5.8	97	450
University of Alaska, Fairbanks	Not Tested				0
University of Alberta	840	45	59.6	67	289
University of Idaho	625	59	29.7	83.5	368
University of Kansas	Not Tested				0
University of Waterloo	617	60	66.5	63	296
University of Wyoming	599	61	93.1	48	0
CONTROL SNOWMOBILE	1524	N/A	180.2	N/A	N/A

It should be emphasized that the power levels used to calculate the emissions levels in Table 4 were indicated (uncorrected) power, as measured from the sled track. Laboratory snowmobile emissions (as in the ISMA 5-mode steady-state test procedure) are determined using an engine dynamometer with power measured at the engine crankshaft. The results of these two types of tests are, therefore, not directly comparable because they are based on two different types of power measurements.

Four teams were unable to complete emission testing. Colorado State University's engine suffered a mechanical failure, Michigan Tech's drive chain failed, and the teams from Alaska and Kansas were unable to meet the competition schedule for emission testing.

Of the nine teams completing testing, all but the University of Wyoming passed. The University of Wyoming did reduce both CO and HC by more than 60%, but NO_X levels were increased, causing $HC+NO_X$ emissions to just miss the 50% passing criterion.

The University at Buffalo had the best emissions at the SAE CSC2001, with Kettering University close behind. The University at Buffalo snowmobile reduced $HC+NO_X$ by 97% and CO by 82% with a turbocharged, electronically fuel injected (EFI) four-stroke engine with both an oxidizing and three-way catalyst (TWC). Kettering University reduced $HC+NO_X$ by 98% and CO by 79% with its "off the shelf" turbocharged EFI four-stroke with a TWC. These two snowmobiles were better calibrated than the other snowmobiles tested at the SAE CSC2001. All teams in the competition could have achieved further reductions in emissions with more time spent on engine and drivetrain calibration.

4.2. Fuel Economy/Range Test[⋆]

All SAE CSC2001 snowmobiles attempted to complete a 96 mile trip in Yellowstone National Park. Participants were required to maintain a speed equal to

[⋆] Portions of Section 4.2 were written by Mr. John Daily, Jackson Hole Scientific Investigations, Jackson, Wyoming.

the legal speed limit, which varied from 35 to 45 miles per hour. The required speed was occasionally reduced for safety in poor driving conditions.

Trail conditions were four inches of wet snow on top of a hard pack of groomed snow. The temperature during testing was approximately 28°F.

Snowmobiles began the trip will full tanks. The amount of fuel required to fill the tank upon return was used to award points for this event.

Teams received 100 points for completing the event. An additional 100 points were available based upon teams' fuel economy improvement. Individual team results for the fuel economy/range event are listed Table 5.

Of the twelve snowmobiles that began the fuel economy/range test, only four snowmobiles finished. Some problems encountered were minor (one team had an air bubble in its cooling line - remaining after emission testing), but overall the event served to "weed out" teams whose solutions were not durable or "not quite ready".

The University of Waterloo had the best fuel economy at the SAE CSC2001. This entry increased fuel economy to 19.3 mpg from the control snowmobile's 12.2 mpg fuel economy, a 58% improvement.

4.3. Noise Test

All SAE CSC2001 snowmobiles were subjected to noise measurements intended to determine the maximum exterior sound level possible from the competing snowmobiles. Noise measurements were taken in accordance with SAE J192 (18), the SAE recommended practice for measuring the exterior sound level from snowmobiles. This test procedure measures snowmobile noise while under wide open throttle acceleration, with measuring equipment located 50 ft from the road. Tests were performed on both sides of the snowmobile. The noise level measurements were taken in conjunction with the acceleration event, which ensured that snowmobiles were operating at wide-open throttle.

Tests were run until three readings within a 2 dBA range per snowmobile side were obtained. The sound level recorded for each side of the snowmobile was

Table 5 *Results of the Fuel Economy/Range Event, Noise Test, and Acceleration Test*

Participant	Fuel Economy (MPG)	Fuel Economy Points	Maximum Sound Level dBA	Noise Test Points	Best Acceleration (seconds)	Acceleration Points
Clarkson University	Did not finish (DNF)	0	77	0	7.123	87.9
Colorado School of Mines	DNF	0	79	0	10.031	20.6
Colorado State University	Not Tested	0	Not Tested	0	Not Tested	0
Kettering University	DNF	0	72	138.4	7.532	73.5
Michigan Tech.	DNF	0	79	0	7.408	77.6
Minnesota State University	17.4	151	77	0	7.520	73.9
University at Buffalo, SUNY	DNF	0	67	250	12.175	0
University of Alaska	15.0	100	73	118.8	8.160	55.6
University of Alberta	DNF	0	74	100	9.013	36.9
University of Idaho	19.0	193	75	0	8.278	52.6
University of Kansas	DNF	0	76	0	6.824	100
University of Waterloo	19.3	200	74	100	9.539	27.8
University of Wyoming	DNF	0	75	0	14.515	0
Control Snowmobile	15.0	Not Applicable	78	Not Applicable	7.393	Not Applicable

recorded as the average of all three readings, rounded to the nearest integer. The sound level used for scoring purposes was that for the side of the snowmobile with the highest reading.

The instrument used for the testing was a Quest Technologies M2400, #JN4070101. The instrument was allowed to equilibrate to ambient temperature for the hour it took to set up the speed trap for the acceleration event. The instrument was calibrated using the calibrator supplied with the instrument, with appropriate corrections for ambient conditions.

The instrument was oriented vertically, with the microphone set 1.5 m (60 inches) above the hard snow surface. A windscreen was in place. Background noise was between 35 to 45 dBA.

The test track was set up near the Cathedral Group turnout in Grand Teton National Park. The snow surrounding the track was about two feet deep of hard pack, covered with 4 inches of fresh snow. The elevation of the test site was 1920 meters (6295 feet) above sea level. The temperature during testing was in the mid 20s (°F). Wind speed varied from calm to an occasional 8 mile/hour gust.

Snowmobiles 74 dB or quieter measured on the A-weighted scale, 50 feet from the road, passed the noise event and received 100 points. Snowmobiles quieter than 74 dB were awarded up to 150 additional points, based upon their relative improvement. Results are presented in Table 5.

Of the twelve snowmobiles tested, five passed the noise event. Two teams (Idaho and Wyoming) were very close to passing the event with a high measurement of 75 dBA.

The University at Buffalo’s snowmobile achieved particularly impressive reductions in noise levels (67 dBA, at wide-open-throttle, 50 feet from the road). However, this entry failed the acceleration event and was ineligible to win the award for the quietest snowmobile. The quietest snowmobile with acceptable performance was the snowmobile from Kettering University, with a sound level of 72 dBA.

4.4. Acceleration Test

The acceleration event was scored on the basis of elapsed time to 500 feet from a standing start. Student participants drove their own snowmobiles in this event. The event comprised the best of six runs for which valid noise data was also obtained.

SAE CSC2001 acceleration testing took place at the Cathedral Group Turnout in Grand Teton National Park. Conditions were as described in the Noise Test Description.

JACircuits timing equipment was used to measure the elapsed time from 0 to 500 feet for this event. This equipment measures elapsed time between two points using a pulsed infrared light beam at the start and finish line. The timing circuit was calibrated by Performance Timing Systems, to 0.001 seconds. The limit of resolution of the timing equipment was 0.001 seconds.

All snowmobiles in the SAE CSC2001 were expected to complete this event with a time of less than 12 seconds. Teams failing the event received 0 points and became ineligible to receive the award for the quietest snowmobile.

Teams passing the event received up to 100 points, based on their relative performance in the event. Individual team results for the acceleration event are listed in Table 5.

The University of Kansas won the acceleration event, improving the elapsed time to 500 feet from a standing start by almost 0.6 seconds (over the control). Kansas, however, did not pass the noise test. In fact, no teams faster than the control snowmobile passed the noise event. However, four schools were able to pass both the noise and acceleration tests, with Kettering University coming within 0.14 seconds of the control sled’s acceleration time while simultaneously reducing emissions to 72 dBA.

4.5. Hill Climb Event

All participants in the SAE CSC2001 were required to compete in the World Championship Snowmobile Hill Climb. The hill climb event was scored based on maximum height reached or elapsed time to reach the top of a course up Snow King

Mountain. The course was approximately 3000 feet long, had an average grade of 19 degrees (39%), and a maximum grade of 30 degrees (60%). Professional snowmobile drivers rode the snowmobiles in this event. Individual team results for the hill climb event are listed in Table 6.

Table 6 *Results of the Hill Climb*

Participant	Maximum Height	Time to Top	Hill Climb Points
Clarkson University	Top	60.19 s	81.3
Colorado School of Mines	4th High Mark		1
Colorado State University	Did not compete		0
Kettering University	2nd High Mark		24.5
Michigan Tech.	1st High Mark		32
Minnesota State University	Top	56.78 s	92.1
University at Buffalo,	3rd High Mark		8
University of Alaska	2nd High Mark		24.5
University of Alberta	1st High Mark		32
University of Idaho	Top	75.21 s	50
University of Kansas	Top	71.18 s	56.5
University of Waterloo	Top	54.61 s	100
University of Wyoming	5th High Mark		1

4.6. Handling Event

The handling capabilities of each modified snowmobile were evaluated by professional snow cross drivers. Drivers based their evaluation on the snowmobiles' cornering, ride, engine response, braking, clutching, and overall performance.

A maximum of 50 points was available for the handling event. Individual team results for the handling event are listed in Table 7, the point summary of the competition.

4.7. Cold Start Event

Because cold starting is essential in a snowmobile, the SAE CSC2001 cold start event was a pass/fail event. SAE CS2001 snowmobiles were cold-soaked overnight. Teams had exactly one minute to start their snowmobile. Snowmobiles that started within 60 seconds passed the cold start event and received 100 points. Cold start testing took place at -6°C (22 °F).

Individual team results for the cold start event are listed in Table 7, the point summary of the competition.

4.8. Engineering Design Paper

This event required SAE CSC2001 teams to write an engineering design paper describing their snowmobile modifications. Students were expected to explain why modifications were performed and document the results of their snowmobile development and testing. Students were also expected to include a detailed cost analysis of their modifications (including justification for any increased cost of the snowmobile). Finally, teams were expected to address the durability and practicality of any modifications.

SAE CSC2001 engineering design papers were judged on content, organization, use of graphics, and references.

A maximum of 100 points was available for the engineering design paper event. Individual team results for the engineering design paper event are listed in Table 7, the point summary of the competition.

4.9. Oral Presentation

Each SAE CSC2001 team made a ten-minute oral presentation on the rationale and approach to their snowmobile modifications. A five-minute question and answer period followed each presentation.

Table 7 *Summary of Points Awarded to Teams in the SAE CSC2001*

Participant	Emission Points	Fuel Economy Range Points	Accel. Points	Noise Points	Hill Climb Points	Handling Points	Cold Start Points	Design Paper Points	Oral Design Pres. Points	Static Display Points	Penalties	FINAL SCORE
Clarkson University	378	0	87.9	0	81.3	31	100	23.8	35.6	27.1	-50	**744**
Colorado School of Mines	328	0	20.6	0	1	0	100	61.3	50.4	25.8	-25	**562**
Colorado State University	0	0	0	0	0	0	0	71.5	62.6	36.3	0	**170**
Kettering University	445	0	73.5	138.4	24.5	38	100	70.8	74.8	43.8	0	**1009**
Michigan Tech.	0	0	77.6	0	32	19	100	75.3	76.8	38.9	-50	**370**
Minnesota State University	375	151	73.9	0	92.1	50	100	59.0	54.8	41.3	-25	**972**
University at Buffalo,	450	0	0	250	8	15	100	68.7	73.1	44.8	-25	**983**
University of Alaska	0	100	55.6	118.8	24.5	37	100	68.5	55.4	34.9	-35	**561**
University of Alberta	289	0	36.9	100	32	30	100	76.5	58	38.8	0	**761**
University of Idaho	368	193	52.6	0	50	47	100	38.2	55.4	42.2	0	**946**
University of Kansas	0	0	100	0	56.5	38	100	50	58.7	32.4	-80	**356**
University of Waterloo	296	200	27.8	100	100	31	100	77.3	57.9	38.1	-10	**1018**
University of Wyoming	0	0	0	0	1	3	100	31	61.7	31.8	0	**228**

In their presentation, teams were expected to clearly state how their modified snowmobile addresses the needs of snowmobilers (performance), land managers and those concerned about the environment (noise and emissions), and snowmobile tour operators (cost, durability/re-sale value).

SAE CSC2001 oral presentations were judged on content, format, delivery, effectiveness of visual aids, and ability to answer judges' questions. A maximum of 100 points was available for the oral presentation event. Individual team results for the oral presentation event are listed in Table 7, the point summary of the competition.

4.10. Static Display

As part of the SAE CSC2001, each team placed their snowmobile on display at the World Championship Hill Climb, held March 30th through April 2nd in Jackson Hole, Wyoming. Static displays were expected to encourage visitors to purchase the prototype snowmobiles and educate visitors about the need to reduce noise and emissions from snowmobiles. Teams were encouraged to put up signs, hand out flyers, and use any other marketing techniques to attract attention to their prototype snowmobile.

SAE CSC2001 static displays were judged on aesthetics, student knowledge, handouts/posters, and overall impression. A maximum of 50 points was available for the static display event. Individual team results for the static display event are listed in Table 7, the point summary of the competition.

4.11. Penalties Assessed During the CSC2001

SAE CSC2001 participants received penalty points for arriving late at the competition, submitting their engineering design paper late, performing unscheduled maintenance on their snowmobile, and/or violating competition safety rules. The penalty points assessed during the SAE CSC2001 are summarized below:

- Clarkson University, -25 points for unscheduled maintenance and –25 points for a safety violation
- Colorado School of Mines, -25 points for unscheduled maintenance

- Michigan Technological University, -50 points for unscheduled maintenance
- Minnesota State University, -25 points for unscheduled maintenance
- University at Buffalo, -25 points for unscheduled maintenance
- University of Alaska, -10 points for a late paper and –25 points for a late snowmobile
- University of Kansas, -30 points for a late paper and –50 points for unscheduled maintenance
- University of Waterloo, -10 points for a late paper

4.12. Technology Implementation Cost Assessment

As part of the SAE CSC2001, each team was required to submit a technology implementation cost assessment (TICA) on their modified snowmobile. The TICA's purpose was to provide a standard method to compare the "manufacturer's cost" (cost TO the end snowmobile manufacturer) of each team's strategy for reducing emissions, noise, and fuel consumption. The TICA was not intended to evaluate the manufacturer's cost of "secondary" modifications such as suspension modifications or more comfortable seats.

No points or penalties were associated with a team's technology implementation total cost (TITC). TITC's were only used to help determine winners of the awards for Most Practical Solution and Best Value. Final TITC's are listed in Table 8.

4.13. Summary of Competition Winners

The points awarded to each team in the competition are summarized in Table 7. The final standings of the participants in the SAE CSC2001 are listed in Table 9.

Table 8 *SAE CSC2001 Cost Assessment*

Participant	TITC
Clarkson University	\$1,084.83
Colorado School of Mines	\$981.55
Colorado State University	\$698.50
Kettering University	\$1071.96
Michigan Tech.	\$918.42
Minnesota State University	\$954.60
University at Buffalo, SUNY	\$1,949.10
University of Alaska	\$1,652.27
University of Alberta	\$1,136.70
University of Idaho	\$948.75
University of Kansas	\$1170.38
University of Waterloo	\$724.50
University of Wyoming	\$652.96

Table 9 *Final SAE CSC2001 Standings*

Participant	Total Points	Order of Finish
University of Waterloo	1018	1st
Kettering University	1009	2nd
University at Buffalo	983	3rd
Minnesota State University	972	4th
University of Idaho	946	5th
University of Alberta	761	6th
Clarkson University	744	7th
Colorado School of Mines	562	8th
University of Alaska	561	9th
Michigan Tech.	370	10th
University of Kansas	356	11th
University of Wyoming	228	12th
Colorado State University	170	13th

In addition to awards for final overall standing, several category awards were presented to SAE CSC2001 competitors. They are listed below.

- *Best Emissions:* University at Buffalo, SUNY
- *Best Fuel Economy:* University of Waterloo
- *Quietest Snowmobile:* Kettering University
- *Best Design:* Kettering University[1]
- *Best Performance:* University of Waterloo[1]
- *Best Value:* University of Waterloo[2]
- *Most Practical:* University of Waterloo[3]
- *Hill Climb Champion:* University of Waterloo[1]
- *Most Sportsmanlike:* University of Kansas

[1] Teams were required to pass noise and emissions to be eligible to receive this award.

[2] The award for Best Value was awarded to the team with the best balance between cost, fuel economy, and performance.

[3] The award for Most Practical was presented to the team with the best balance between cost, noise reduction, and emission reduction.

5. CONCLUSION

The SAE CSC2001 concluded with a tight finish. The top five finishers in the competition were separated by less than 72 points. Any one of the teams finishing in 2nd-5th place could have won the competition if they had passed all competition events (#2 Kettering did not complete the fuel economy/range event, #3 Buffalo did not complete the fuel economy/range event and just missed passing acceleration, #4 Minnesota State did not pass noise, and #5 Idaho just missed passing noise).

In the end, the reliable two-stroke snowmobile from the University of Waterloo walked away with the top prize in the SAE CSC2001. The winning entry from the University of Waterloo earned the distinction of being the only snowmobile in the competition to complete and pass every event. This entry is also one of the least expensive solutions, according to the SAE CSC2001 technology implementation cost assessment. Through its success at the SAE CSC2001, the University of Waterloo has demonstrated that modified two-stroke engines can be a very cost-effective method to achieve large reductions in emissions and noise without a significant sacrifice in performance.

The University of Kettering entry took second place in the SAE CSC2001 with a snowmobile featuring an "off-the shelf" turbocharged four-stroke engine with catalytic aftertreatment. The Kettering entry was also successful at reducing noise and emissions while simultaneously maintaining adequate performance (it had the fastest acceleration of the snowmobiles that passed the noise test). According to the Kettering design paper (13), the total cost of the engine, turbocharger, electronic control module, and catalyst is $600. This commercially available solution also shows promise as a cost-effective design to help reduce the impact of snowmobiles on the environment.

With both two-stroke and four-stroke snowmobiles finishing in the top five and achieving impressive noise and emission reductions, it is clear that the battle between the two technologies is far from over.

6. ACKNOWLEDGEMENTS

The SAE CSC2001 would have been impossible without the sponsorship of the following organizations: United States Environmental Protection Agency, Flagg Ranch Resort, Montana Department of Environmental Quality, Wyoming Department of Environmental Quality, International Snowmobile Manufacturers Association, Teton County WY, Peaks to Prairies Pollution Prevention Information Center, U.S. Department of Energy (Pacific Northwest and Alaska Regional Bioenergy Program), WestStart, Jackson Hole Mountain Resort, Jackson Hole Snow Devils, Sports Car Club of America, Town of Jackson, Wyoming Business Council, Blue Ribbon Coalition, Dana Corporation/Long Manufacturing Ltd., Dynojet Research, Inc., Life Enrichment Foundation, MDEChem/PG Formula Company, Inc., National Park Service, Redline Snowmobiles, Snow King Resort, Utah Snowmobile Association, Wyoming Ethanol, Washington State Snowmobile Association, Western Chapter International Snowmobile Council, Wyoming State Snowmobile Association, California-Nevada Snowmobile Association, New York State Snowmobile Association, Sweetwater County Snowpokes.

We would also like to acknowledge the following organizations/individuals for the in-kind support they provided to the competition: Action Snowmobile & RV Inc., Albertson's Food and Drug, Amfac Parks and Resorts, Arctic Cat, Bank of Jackson Hole, Bechtel BWXT Idaho, Blue Ribbon Coalition, Bob Walker, Bridger Teton National Forest, Central Wyoming College, Cowboy Village Resort at Togwotee, Dynojet Research, Inc. , ETAS, Inc., Ethanol Producers and Consumers, Flagg Ranch Resort and Staff, Grand Teton National Park & Staff, High Country Linen Service, Howdy Partners, Hughes Production Company, INEEL, Institute of Science, Ecology, and the Environment, International Snowmobile Manufacturers Association, International Snowmobile Racing, Jackson Hole Chamber of Commerce, Jackson Hole Conservation Alliance, Jackson Hole Mountain Resort, J H Scientific Investigations, Jackson Hole Snow Devils, The Jackson State Bank, Jean Welch, Jeff McCallister, Jerry Fussell, JDR Memorial Parkway and Staff, K Mart, The Liquor Store, Marilyn Paine, Mc Donald's of Jackson Hole, Inc., Mini Mart of Jackson Hole, Montana DEQ, Napa Auto Parts, Old Faithful Snowmobile Tours and

Staff, Polaris Industries, Inc., Redline Snowmobiles, Rocky Mountain Guides Association, SAE Foundation, SAE International, Shervin's Independent Oil, Snake River Associates, Snow King Resort, Southwest Research Institute, Sports Car Club of America, Susan Crosser, Teton County Wyoming, Teton Rental Center & Ski-Doo, Togwotee Snowmobile Adventures, Toolson Telephone, Town of Jackson Wyoming, U.S. Department of Energy, Utah Snowmobile Association, Wyoming Business Council, Wyoming DEQ, WY Department of State Parks, Wyoming Guides Association, WY State Snowmobile Association, Wyoming State Trails, Yamaha Motor Corporation, Inc., Yellowstone National Park & Staff.

We would like to acknowledge the following individuals for their dedication to the development and organization of the SAE CSC2001: Teton County Commissioner Bill Paddleford, Mrs. Lisa Paddleford, Dr. Jerry Fussell, Mr. Robert Sechler, Mr. Jim Evanoff, Mr. Bob Walker, Mr. Howard Haines, the SAE CSC2001 Rules Committee, and the SAE CSC2001 Advisory Board.

Finally, we express our appreciation to the faculty and students of our participating universities. We are grateful for your dedication, innovation, and enthusiasm.

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Appendix A

The SAE Clean Snowmobile Challenge 2001 Rules

The SAE Clean Snowmobile Challenge 2001 Rules
Final Version - June 30, 2000
Revised September 25, 2000

Administered by:
The Society of Automotive Engineers,
Institute of Science, Ecology, and the Environment,
Teton County Commissioner Bill Paddleford,
and
Dr. Lori M. Fussell

The SAE Clean Snowmobile Challenge 2001 Rules
Final Version - June 30, 2000
Revised September 25, 2000

Table of Contents

1. BACKGROUND

1.1 Introduction

The Clean Snowmobile Challenge 2001 (CSC2001) is an engineering design competition for college and university student members of the Society of Automotive Engineers (SAE), organized and administered by the SAE, the Institute of Science, Ecology, and the Environment (ISEE), Mr. Bill Paddleford, and Dr. Lori Fussell. Competition organizers will allow up to fifteen teams to compete in the CSC2001. Selection for competition in the CSC2001 will be given to schools submitting the best proposals for re-designing a snowmobile to improve its emissions and noise while maintaining its performance characteristics. At the present time, sponsorship and support for the CSC2001 is being provided by: Teton County Wyoming, The Montana Department of Environmental Quality, The Environmental Protection Agency, WestStart, Yellowstone National Park, Grand Teton National Park, The Jackson Hole Snow Devils, The Jackson Hole Chamber of Commerce, Jackson Hole Mountain Resort, The Wyoming Department of Environmental Quality, Old Faithful Snowmobile Tours, Flagg Ranch Resort, The Department of Energy, Town of Jackson, Dynojet, and Southwest Research Institute. The modified snowmobiles will compete in Jackson, Wyoming beginning on March 23, 2001 in a variety of events including emissions, noise, fuel economy/range, acceleration, power, and design. Prize money totaling $32,000 will be awarded at the end of the competition on March 30, 2001.

1.2 Competition Objective

The intent of the competition is to develop a snowmobile that is acceptable for use in environmentally sensitive areas. The modified snowmobiles are expected to be quiet, emit significantly less unburned hydrocarbons and carbon monoxide than conventional snowmobiles (without significantly increasing oxides of nitrogen emissions), and maintain or improve the performance characteristics of conventional snowmobiles. The modified snowmobiles are also expected to be cost-effective; so that snowmobile outfitters can afford to purchase them and still make a profit running tours. Although the snowmobiles will compete in both a hill climb event and a handling event to evaluate performance, the intent of the competition is to design a touring snowmobile that will primarily be ridden on groomed snowmobile trails. The use of unreliable, expensive solutions is strongly discouraged!

2. ELIGIBILITY

2.1 University Eligibility

Engineering proposals will be accepted from student teams at accredited colleges and universities. High school teams will not be permitted to participate.

2.2 Team Member Eligibility

Undergraduate participation is strongly encouraged. Graduate student participation is allowed, but limited to no more than 25% of the undergraduate participation on any individual team.

2.3 University Collaboration

Collaboration between schools will be accepted if both schools meet all requirements stated in these rules.

2.4 Required Engineering Proposal

A college or university team wishing to participate in the CSC2001 must submit an engineering proposal covering the conversion of a snowmobile.

2.5 Participant Selection

A review panel will select up to fifteen (15) teams to participate in the CSC2001 based on the quality of their engineering proposal.

2.6 CSC2001 Permitted Participants

Only teams selected by the review panel may participate in the CSC2001. Teams not selected by the review panel may not participate in the CSC2001.

2.7 SAE Membership/Driver's License

All participants must be student members of the Society of Automotive Engineers (SAE) with a valid membership card. Applications for membership will not suffice. All snowmobile drivers must have a valid driver's license.

2.8 Medical Insurance

All snowmobile drivers must present proof of medical insurance coverage that is valid in the United States.

3. ENGINEERING PROPOSAL REQUIREMENTS

3.1 Design Criteria

The proposed design should assume that a snowmobile is being developed for use on groomed trails in environmentally sensitive areas. Carbon monoxide (CO) emissions should be a *minimum* of 25% less than the CO emissions of traditional snowmobiles. Unburned hydrocarbon (UHC) emissions should be a *minimum* of 50% less than the emissions from traditional snowmobiles. Oxide of Nitrogen (NOx) emissions should not be increased significantly. Particulate emissions should also be reduced, but it is not known if particulates will be measured in the SAE CSC2001. The snowmobiles may be fueled by gasoline, oxygenated gasoline (10% ethanol), or electricity (hybrid-electric). Both two-stroke (600cc or less) and four-stroke (960cc or less) solutions are permitted. Snowmobile power should be maintained or improved and will be evaluated with an acceleration run, a handling event, and a hill-climb event. Noise will be measured during the acceleration run and must not exceed 74dBA, 50 feet from the road.

3.2 Engineering Proposal Content

Engineering proposals must describe the design approach to be taken by the student team, together with the design rationale, including detailed descriptions of the engine, fuel system, ignition system, and intake and exhaust systems. Designs will be judged on the appropriateness and creativity as well as on cost-effectiveness. Included in the proposal or attachments should be a description of the facilities available to assist in the conversion process, and the qualifications of the students and faculty advisor to compete successfully in the CSC2001. Also required with the proposal or attachments is a schedule of milestones for the snowmobile conversion and development program, including a milestone for transporting the snowmobile to the event. The maximum limit of 10 pages of text and 5 pages of supporting attachments will be strictly enforced, except as needed for alternative accessible formats.

3.3 School Support

Evidence of school support and approval must be provided in a letter signed by the dean of the school of engineering (or the equivalent) of the participating school(s) and must accompany the engineering proposal. Failure to include this letter will disqualify the proposal from consideration.

3.4 Faculty Advisor and Team Captain

The name, phone number, fax number, and email of both the team captain and faculty advisor assigned to this project must be submitted with the proposal.

3.5 Submission Deadline

Dr. Lori Fussell must receive FIVE COPIES of the typed proposal no later than May 30, 2000. Send the proposals to Dr. Lori M. Fussell, 2570 Teton Pines Drive, Wilson, WY 83014. No hand written proposals will be accepted.

3.6 Engineering Proposal Review

A review committee of experts from the automotive industry and research community will evaluate the engineering proposals.

3.7 Engineering Proposal Evaluation Criteria

Engineering proposals will be judged on appropriateness, quality, creativity, durability, and cost-effectiveness of the conversion. Special emphasis will be given to innovative and practical approaches to reducing noise and emissions. The engineering proposal review form will contain the following categories and point allocation:

Overall Approach/Design Rationale:	20 points
Emission Control:	15 points
Noise Reduction:	15 points
Power Retention:	10 points
Facilities:	10 points
Faculty Advisor and Team:	10 points
Timeline:	10 points
Overall Impression:	10 points

3.8 Review Committee Decision

Due to limited emission testing facilities, only 15 teams will be selected to compete in the SAE CSC2001. However, if in the opinion of the review committee, the number of acceptable proposals is less than 15, a corresponding number of teams will be selected for participation. The decision of the review committee is final.

3.9 Results Announcement

Engineering proposal review results will be announced by July 1, 2000.

4. SNOWMOBILE MODIFICATION

4.1 Baseline Snowmobile

Participants in the CSC2001 are expected to provide their own snowmobile for modification. There is no restriction on the baseline snowmobile as long as the final modification meets all CSC2001 rules. ***However, intent of the CSC2001 is for student teams to modify an existing snowmobile to improve emissions and noise characteristics.*** Teams choosing to ignore this intent by entering a snowmobile made clean and quiet by a manufacturer or aftermarket supplier will be disqualified. Competition organizers will be responsible for making this subjective determination, if necessary.

4.2 Engine

4.2.1 Permitted Modifications

Modifications to the engine, including substitution of a different engine are allowed.

Both two-stroke, four-stroke, and rotary engines are allowed. Engine displacement is limited to 600 cc or less for two-stroke and rotary engines, 960 cc or less for four-stroke engines.

Electric and hybrid electric snowmobiles are allowed. *However, CSC2000 organizers will be unable to measure the emissions from hybrid electric snowmobiles. Therefore, hybrid electric snowmobiles will be ineligible for the Best Emissions Award in addition to the awards for First through Fifth Place. Hybrid Electric Snowmobiles will be eligible to compete for all other competition awards. Additionally, there will be a specially created award for the Best Hybrid Electric Snowmobile, as specified in CSC2001 Rule 8.1.*

4.2.2 Permitted Fuels/Additives

Snowmobiles may be fueled by gasoline, a blend of 10% ethanol and 90% gasoline, or electricity. Fuel choice must be selected by October 1, 2000 as specified in CSC2001 Rule 6.5. Fuel additives (with the exception of commercial two-stroke oil) are not permitted.

4.2.3 Lubricating Oils

There are no restrictions on the type of oil to be used in the modified snowmobile. However, the same type of oil must be used throughout the CSC2001. Oil must be added in the presence of a CSC2001 official and must come from a factory sealed container.

4.2.4 Turbochargers/Superchargers

The use of turbochargers and superchargers is allowed. All turbochargers and superchargers must have a restraint system to prevent them from being flown free of the engine; this includes a flexible blanket shield.

4.2.5 Exhaust Systems

The exhaust system may be modified, but must meet or beat sound and emission standards detailed in CSC2001 Rules 9.8 and 9.9. The exhaust system emission pipe must not protrude more than three (3) inches beyond the chassis or hood configuration.

4.2.6 Throttle Requirements

An adequate return spring on the throttle is required. The throttle must remain on the right side. The throttle will be operated with a direct mechanical operated thumb mechanism located on the handlebar to the rear of the machine (no twist grips).

4.3 Drive

4.3.1 Drive Modification Allowed

The snowmobile drive may be modified.

4.3.2 Transmission

The snowmobile must be propelled with a variable ratio belt transmission. Hybrid-electric and electric snowmobiles are exempt from this requirement.

4.3.3 Brake Performance Requirement

All brake modifications are subject to retaining the braking performance of the original snowmobile. This will be tested during the safety/tech inspection before snowmobiles are allowed to compete in the CSC2001.

4.3.4 Brake Control Handle

The brake control handle must remain in the OEM location (left side). Brakes must be operative at all times.

4.3.5 Brake System

The master cylinder, caliper and disc assembly must be commercially available.

4.3.6 Secondary Brake

If the secondary brake is on the track shaft, the disk may be smaller than 7”. Additional brake assemblies may be added. Brake disc on drive axle track shaft must be at least seven (7) inch minimum diameter. Axle shaft may be lengthened to accommodate additional brakes.

4.3.7 Brake Disk Shield

Brake disc must be covered with a shield capable of retaining an accidental explosion.

4.3.8 Disc Contact Area

The disc pad contact surface area may not be reduced more than 15% of the original pad contact surface area.

4.3.9 Clutch Cover Guards

Clutch cover guard must be separate of the cowl configuration, and cover clutch to center of bolt or below. It must be made of 0.090 inch 6061 T6 aluminum or equivalent and be covered with 6 inch belting. Snowmobiles with removable side panels may bolt clutch cover guard to side panel to meet this requirement.

4.3.10 Moving Parts Isolation

Chains, pulleys, and exposed moving parts will be isolated from the driver and other competitors by shields capable of retaining all accidental explosions and component impacts. No holes may be drilled in protective shields.

4.4 Skis and Ski Suspension

4.4.1 Ski and Ski Suspension Modification

The snowmobile's skis and ski suspension may be modified. However, the snowmobile must remain ski-steered

4.4.2 Ski Requirements

Skis must be commercially available. The use of carbides is not allowed.

4.4.3 Suspension Requirements

Sleds must have a minimum of one (1) inch usable ski suspension and a minimum of one (1) inch travel in usable track suspension. Usable means with rider on sled. Only steel springs are allowed.

4.5 Track, Track Suspension, and Traction

4.5.1 Track and Track Suspension Modification

The snowmobile's track may be replaced with a different track. The track must be a commercially available, one piece, molded rubber snowmobile track. The selected, commercially available track may not be modified. The snowmobile's track suspension may be replaced and/or modified.

4.5.2 Minimum Track Width

Minimum combined or single-track width is fifteen (15) inches. A 1/8 inch maximum variance in the minimum track width requirement is allowed. No notching or trimming of the track is allowed.

4.5.3 Minimum Belt Width

This rule has been removed.

4.5.4 Traction Control Devices

The use of traction control devices such as studs, ice growsers, or paddles is not allowed.

4.5.5 Slide Rail Hyfax

Slide rail hyfax can be drilled. OEM type slide rail hyfax may be used as a replacement.

4.5.6 Slide Rail Lubrication

Slide rail lubrication systems are not allowed. Slide rail inserts may be added.

4.5.7 Maximum Track Lug Length

The maximum length of track lugs is 1.5 inches.

4.6 Frame and Body

4.6.1 Rear Snow Flap

A rear snow flap of sufficient material to restrain traction components if thrown from the track will be installed in a permanent manner and shall be held down so as to contain all mud, snow, rocks, water, etc., at all speeds. The snow flap must overlap from outside of tunnel to outside of tunnel, one (1) inch outside the widest part of the rear tunnel opening. The snow flap must be in contact with the course surface when the rider is on the sled.

4.6.2 Snow Flap: Twin Track

The snow flap on twin track sleds must be reinforced to keep it in proper placement at racing speeds. Two (2) separate flaps may be used on twin track sleds.

4.6.3 Snow Flaps: Fastening

The use of springs and/or elastic material for holding down and fastening snow flaps is not acceptable.

4.6.4 Snow Flaps: Wheelie Bars

Material used in/as wheelie bars will not be considered a snow flap.

4.6.5 Foot Stirrups/Pegs

Foot stirrups/foot pegs constructed of rigid materials may be installed.

4.6.6 Seat

All sleds will be equipped with an upholstered, padded seat with a minimum thickness of one (1) inch, a length of twenty-four (24) inches, and a width of the tunnel.

4.6.7 Body Modification

The snowmobile body may be modified. The hood must have top and side cowling and must contain at least one thousand three hundred (1300) square inches.

4.6.8 Front Bumper Requirement

All snowmobiles must have a front bumper strong enough to support the snowmobile while suspended in mid-air (for ease of lifting).

4.6.9 Decal Space Requirement

Two hundred (200) square inches of space must be left free on the hood/tunnel of the snowmobile for sponsorship decals to be placed upon arrival in Jackson Hole, WY.

4.6.10 Team Number

The team number must appear on both sides of the snowmobile hood. The number must be six (6) inches high, ¾ inches wide, and be displayed in contrasting colors. The team number must also be displayed in contrasting colors on both sides of tunnel, minimum of four (4) inches high.

4.6.11 Fuel Choice Label

The snowmobile fuel choice must be clearly labeled in contrasting colors on the snowmobile fuel cap and/or next to the snowmobile fuel cap.

4.6.12 Chassis Modification

The snowmobile chassis (bulkhead and tunnel) must be commercially available. Teams are not permitted to build their own chassis from the ground up. No modifications may be made to the snowmobile chassis that will reduce structural integrity.

4.7 Ignition and Electrical

4.7.1 Safety Disconnect Tether

All machines must be equipped with a safety disconnect tether that is operable at all times. Safety disconnect tethers must be used and attached to the operator whenever the engine is running. Maximum tether cord length will be five (5) feet. Verification of the tether cord length will be determined at tether cords fully extended length. The tether cord will be securely fastened to the driver. No alligator clips are allowed. The tether switch will be securely mounted in a location on the snowmobile other than on the handlebars.

4.7.2 Battery Fuel Pumps

Battery operated electric fuel pumps must be connected to the tether switch. This includes electrically controlled fuel injection systems.

4.7.3 Battery Box Requirements

Wet cell must be enclosed in a non-conductive battery box. Positive terminal must be shielded. Battery box must be securely held in place.

4.8 Component Deletion

No changes are allowed that would nullify compliance with federal, state, or provincial safety regulations.

5. QUESTIONS ABOUT AND LOOPHOLES IN THE RULES

5.1 Question Submission

All questions on the CSC2001 Rules must be submitted in written form via fax, letter, or email (no phonecalls) to Stephanie Cornelius, ETAS Inc., 3021 Miller Road, Ann Arbor, MI 48103. Fax: (734) 997-9449. Email: scorneli@etasinc.com. Questions must include the appropriate CSC2001 Rule #.

5.2 Loopholes and Problems

Any perceived loopholes or potential problems should be identified in writing to Stephanie Cornelius at the address listed in CSC2001 Rule

5.1. Suggestions for rule changes must reference the appropriate CSC2001 Rule #, state the current wording of the rule, and contain a suggestion of how the rule should be changed.

5.3 Question Distribution

Copies of all questions along with their answers will be sent via email to all CSC2001 faculty advisors and team captains. Additional team members may be placed on the SAE CSC2001 Rules Question Email List by request to Stephanie Cornelius at the address listed in CSC2001 Rule 5.1. A comprehensive list of all rules questions and their answers will be available on the CSC2001 website (http://www.sae.org/students/cscrulesqa.htm) and in the CSC2001 discussion forum (an SAE discussion forum).

5.4 Engineering Ethics

The Clean Snowmobile Challenge 2001 is an engineering design competition that requires performance demonstration of snowmobiles. It is **NOT** a race. Engineering ethics will apply. In all events violation of the intent of the rule will be considered a violation of the rule.

6. CONDUCT OF THE EVENT

6.1 Safety

The overriding emphasis of the CSC2001 and all its events is on safety. Any unsafe behavior during the CSC2001 will result in disqualification of the student team.

6.1.1 Safety/Technical Inspection

A safety/technical inspection of each snowmobile will be performed after it arrives in Wyoming and before emission testing is performed. If safety or rule violations are found, the team will be promptly notified. The team must correct all safety issues before the snowmobile is permitted to compete in any event, including emissions testing. Passing the safety/technical inspection does not in any way imply that SAE, the CSC2001, or any individuals acting on their behalf certify that the snowmobile is safe for use. It is the sole responsibility of participating teams to insure that their snowmobiles are safe for entry in the CSC2001.

6.1.2 *Safety Disconnect Tether*

Each snowmobile must be equipped with a safety disconnect tether as described in CSC2001 Rule 4.7.1. Twenty-five (25) penalty points will be assessed each time the safety tether is not properly utilized when the engine is on.

6.1.3 *Moving Snowmobiles*

When snowmobiles are driven anywhere but in practice areas, snowmobile trails, or roadways they must be driven at a walking pace. During the performance events when the excitement is high, it is particularly important that the snowmobile be driven at a very slow pace. The walking rule will be enforced and point penalties will be assessed for violations of this rule.

6.1.4 *Support Snowmobiles*

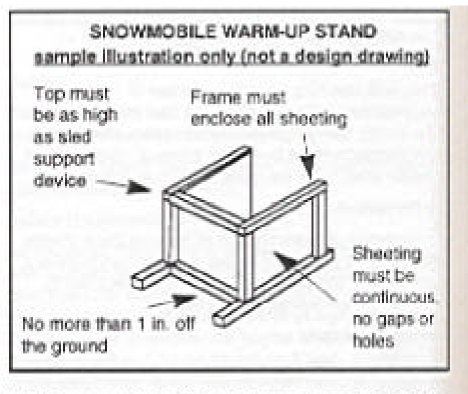
Support snowmobiles may be allowed during certain events. The safety equipment listed in CSC2001 Rules 6.2.1-6.2.2 must be worn at all times any team member is on *any* snowmobile that is in motion. The same penalties described in CSC2001 Rule 6.2.4 will be applied to support snowmobiles.

6.1.5 *Warm up Stands*

Snowmobiles may be warmed up before competing in events. However, this warm-up must take place with the snowmobile mounted in a snowmobile safety stand (you MAY NOT warm up the snowmobile by manually holding the track off of the snow). Twenty-five (25) penalty points will be assessed any time this rule is violated.

The warm-up stand must be designed to catch and retain track, track cleats, traction components and other items that might be thrown by the track. The stand must be no more than six (6) inches from the rear of the tunnel opening and no more than twelve (12) inches from the track. The safety stand will be constructed of metal equivalent to 6061T6 aluminum, 1/8 inch thick. Side panels are mandatory and they must extend at least to the center of the rear axle. The sides and back must be secured inside the framework. Vertical coverage must be no more than one (1) inch off the ice and as high as the snowmobile support device. Coverage must be continuous (no lightening holes). A plywood liner is recommended to help absorb impact. Safety stand must maintain sufficient height to prevent track coming into contact with ground/ice surface. The stand must be used whenever the rear of a machine is raised to clean out the engine or track, and during warm-up.

A sample illustration of a snowmobile warm-up stand is below (courtesy of the International Snowmobile Racing Association).



6.2 Driver Protective Equipment

6.2.1 Helmet Requirement

Full coverage helmets (Snell 95 or newer) are mandatory. The helmet must be securely fastened at all times.

6.2.2 Clothing and Boots

Gloves and clothing, along with at least above the ankle boots are mandatory.

6.2.3 Safety Jacket/Vest

An International Snowmobile Racing (ISR) safety jacket/tech vest as well as shin and knee guards must be worn during the acceleration event.

6.2.4 Penalties

Twenty-five (25) penalty points will be assessed for each individual not wearing appropriate safety gear each time the individual is observed to be in violation of the rule by a CSC2001 official. Appropriate safety gear must be worn any time a snowmobile is in motion.

6.3 On Site Modifications Prohibited

No changes or modifications to snowmobiles will be allowed after emission testing, except for those required to fix safety issues, those required to return the snowmobiles to operating condition after a breakdown, or those considered standard maintenance items as described in CSC2001 Rule 6.4.

Hoods will be sealed and engine calibrations frozen at the beginning of emission testing. Accidental breakage of the seal must be reported immediately. No telemetry will be allowed. Teams are not allowed to remotely alter calibrations during events. No non-standard user input (other than power, ignition, starter and kill switches) is allowed to the powertrain (includes engine intake, base engine, engine exhaust, or drivetrain).

Twenty-five (25) penalty points will be assessed for each 3-hour period of maintenance required (except for maintenance items listed in CSC2001 Rule 6.4) after emission testing has been completed.

In the event that a snowmobile design strategy is “changed” during repairs made after emission testing, the team may continue to compete in CSC2001 events. However, the team will not be eligible to receive any awards for events won after the strategy change.

6.4 Permitted Maintenance Items

The following maintenance items will be allowed throughout the CSC2001 without penalty. Teams must notify and obtain permission from CSC2001 officials before any permitted maintenance items are performed.

- Addition of any fluid – same fluid must be used throughout competition
- Suspension adjustment
- Track alignment and tension adjustment
- Drive belt/chain tension adjustment
- Headlight, taillight, brake light replacement
- Tightening of loose bolts: suspension mounting, suspension front limiter strap, ski saddle, and spindle.
- Lubrication of snowmobile parts
- Tightening of rear idler wheel bolts and idler adjusting bolt jam nuts

- Replacement of spark plugs (same plugs must be used as before…2 changes without penalty…then 5 point penalty per plug).
- Replacement of fuel injectors (same injectors must be used as before or design strategy will be considered to be “changed”…2 changes without penalty…then 5 point penalty per injector).
- Oil/fuel filter replacement

NOTE: The intent of this rule is to allow 1000 mile maintenance items to be performed throughout the CSC2001 without penalty. Organizers reserve the right to modify/add to this list as conditions demand.

6.5 Fuel

Fuel will be provided to all teams throughout the competition. Teams are required to use the provided fuel for all CSC2001 events. Snowmobiles must arrive at the CSC2001 with empty fuel tanks or must be driven to empty before being fueled for emissions testing.

Teams may choose to use either standard gasoline, a blend of 10% ethanol and 90% gasoline, and/or electricity. The same fuel type must be used throughout the event. Those choosing to use electricity must provide their own charging facility.

For organizational purposes, the organizers must be informed of the fuel choice by October 1, 2000. Fuel choice will be submitted electronically via the CSC2001 website at http://www.sae.org/students/snow.htm.

Once teams have selected their fuel, written permission from the organizers is required to switch the fuel choice. The organizers reserve the right to refuse to allow a team to switch their fuel choice after October 1, 2000.

NOTE: hybrid electric snowmobiles will be ineligible to receive the Best Emissions Award and the awards for 1st through 5th place. However, they will be eligible to receive all other CSC2001 awards in addition to a specially created Best Hybrid Electric Snowmobile Award.

6.6 Lubricating Oil

Competing teams are responsible for providing their own lubrication oil (two-stroke or four-stroke). Teams will not be allowed to switch the type of lubrication oil they are using once the competition has begun. Doing so without approval from a CSC2001 official will result in disqualification.

6.7 Electric Snowmobile Charging Facility

Hybrid-electric snowmobiles must provide their own charging facility. A location to plug in the charging facility will be provided.

6.8 Drafting Prohibited

Drafting of other snowmobiles will not be allowed during the fuel economy/range event. Drafting is defined as following another vehicle closer than three snowmobile lengths at cruising speeds for sustained periods of time. Infractions of this rule may be reported by other competitors or by CSC2001 officials. Penalties will be loss of points for the fuel economy/range event (50 points per occurrence).

6.9 Unsportsmanlike Conduct

Unsportsmanlike conduct will not be tolerated. Any driver, crew member, faculty advisor, or spectator who by their conduct detracts from the character of the event, or who abuses, threatens, or uses profane language to an official may be assessed a warning or penalty for unsportsmanlike conduct. A second violation may result in expulsion of the team from the competition. Warnings and penalties may be given by any official and will become record with the approval/concurrence of the organizers.

6.10 Protests and Problems

Any problems that arise during the competition will be resolved through the organizers and the decision will be final. All protests must be in writing and will be subject to a twenty-five (25) point protest bond. If the protest is denied, this amount will be deducted from the final score; if upheld, no points will be deducted. Protests must be filed within one-hour after scores are posted. The decision of the judges and organizers is final.

6.11 Event Appearance and Forfeits

It is the responsibility of the teams to be in the right place at the right time. If a snowmobile is not ready to compete at the scheduled time, then the team forfeits the run of the event and will not be offered a late make-up. The driver for an event will be disqualified if he/she doesn’t attend the driver meeting for the event.

7. SCHEDULE

7.1 Deadlines

7.1.1 *May 30, 2000*

Receipt of five (5) copies of typed student engineering proposals at the address listed in CSC2001 Rule 3.5.

7.1.2 *July 1, 2000*

Participants selected and informed of their selection.

7.1.3 *October 1, 2000*

Fuel choice decided and submitted via the online Fuel Choice Form on the CSC2001 website at http://www.sae.org/students/snow.htm.

7.1.4 *February 14, 2001*

Team program information is due. Team program information will be submitted via the online Program Information Form on the CSC2001 website at http://www.sae.org/students/snow.htm. A *hardcopy* photograph of the team (Black and White preferred, 4”x 6” or less) must also be mailed to Lori Fussell, 2570 Teton Pines Drive, Wilson, WY 83014 by this date.

7.1.5 *March 16, 2001*

Five (5) hardcopies and one electronic copy (MSWord97 format) of the typed, final engineering design paper describing the modified snowmobile are due. The reports should be sent to the address listed in CSC2001 Rule 9.4.1.

NOTE: Late engineering design papers will receive 10 penalty points for each day that they are late, up to a maximum penalty equal to the team’s score for this event.

7.1.6 *March 16, 2001*

One (1) hardcopy and one (1) electronic copy (MSExcel97 format) of the Technology Implementation Cost Assessment (TICA) are due. A copy of all supporting documentation is also due. The TICA information should be sent to Stephanie Cornelius at the address listed in CSC2001 Rule 5.1.

NOTE: All teams will be required to update their TICA at the start of the CSC2001 and have their snowmobile inspected to *verify that their TICA is complete and accurate. Teams not submitting a complete and accurate TICA will be ineligible to receive the awards for Most Practical Solution and Best Value.*

7.2 Event Schedule

7.2.1 March 23, 2001 – Friday

Teams closest to Wyoming - Arrive at Flagg Ranch, WY.

NOTE: Teams will receive 25 penalty points for each day that their snowmobile is late. Late snowmobiles risk loosing the opportunity to have their emissions tested.

7.2.2 March 24, 2001 – Saturday

Teams closest to Wyoming – Safety/Technical Inspection, Fine Tune Altitude Calibration, Complete 100 mile catalyst-aging ride, TICA Inspection.

Teams furthest from Wyoming - Arrive at Flagg Ranch, WY.

7.2.3 March 25, 2001 – Sunday

Teams closest to Wyoming – Emission Testing

Teams furthest from Wyoming - Safety/Technical Inspection, Fine Tune Altitude Calibration, Complete 100 mile catalyst-aging ride, TICA Inspection.

7.2.4 March 26, 2001 – Monday

All participants – Emission Testing

7.2.5 March 27, 2001 – Tuesday

Emission Testing, Oral Design Presentations.

7.2.6 March 28, 2001– Wednesday

Cold Start Test, Fuel Economy/Range Event

7.2.7 March 29, 2001 – Thursday

Acceleration/Noise Event (morning), Handling/Driveability Event (afternoon), Public presentation of selected Oral Presentations (evening).

7.2.8 March 30, 2001 – Friday

Hill Climb (morning), Static Display at hill climb (afternoon), Award Ceremony (evening)

7.2.9 March 31, 2001 – Saturday

Snowmobiles remain on static display at hill climb (mandatory).

7.2.10 April 1, 2001 - Sunday

Snowmobiles remain on static display at hill climb (not mandatory).

8. AWARDS/PRIZE MONEY

8.1 Prize Money

A total of $32,000 will be available for prizes awarded to the top five places overall in the CSC2001, along with special prizes for winning individual events according to the schedule below. The prize money will be given to the winning schools with the understanding that it will be used for future automotive projects.

First Place Overall	$5,000
Second Place Overall	$4,000
Third Place Overall	$3,000
Fourth Place Overall	$2,000
Fifth Place Overall	$1,000
Best Hybrid Electric Snowmobile	$3,000
Best Performance	$2,000
Best Emissions	$2,000
Best Design	$2,000
Best Fuel Economy	$2,000
Quietest Snowmobile	$2,000
Most Practical Solution	$2,000
Best Value	$2,000

8.2 Award Criteria

Best Hybrid Electric Snowmobile	Presented to the hybrid electric snowmobile receiving the highest total point score in the competition.

Best Performance: Presented to the team receiving the highest total score in the Acceleration, Handling, and Hill Climb Events that also passed both the noise and emission event.

Best Emissions: Presented to the team receiving the best score in the emissions event or, in the event of a tie, the lowest hydrocarbon + NOx emissions.

NOTE: Hybrid Electric Snowmobiles will be ineligible to receive this award. Their emissions will not be tested.

Best Design: Presented to the team receiving the highest total score in the Engineering Design Paper, Oral Design Presentation, and Static Display Events that has also received passing scores in the emission, noise, and acceleration events.

Best Fuel Economy: Presented to the team receiving the most points in the Fuel Economy/Range event.

Quietest Snowmobile: Presented to the team receiving the most points in the Noise Event that has also passed the Acceleration Event.

Most Practical Solution: Presented to team with the best balance between cost and measured noise and emission reduction. Winner will be the team with the highest (Noise Points + Emission Points)/Technology Implementation Total Cost.

Best Value: Presented to team with the best balance between cost, fuel economy, and performance. Winner will be the team with the highest (Fuel Economy Points + Acceleration Points + Handling Points + Hill Climb Points + Cold Start Points)/Technology Implementation Total Cost.

8.3 Participation Plaque

Each school will receive a plaque commemorating its participation in the CSC2001. Trophies will be given to the winners in each of the categories listed in Section 8.1 of the CSC2001 rules.

8.4 World Championship Hill Climb

In addition to providing points to each school's overall and performance scores, the hill climb event will be a special class of competition in the World Championship Hill Climb up Snow King Mountain. The school receiving the most points in this event that has also passed both the emissions and noise events will hold the world champion title for our class of competition.

9. SCORING

9.1 Overall Score

Overall scores will be determined, based on a maximum of 1500 points, according to the following schedule:

Event	Points for Passing Event	Maximum Additional Points for Relative Performance in Event
Engineering Design Paper	N/A	100
Oral Design Presentation	N/A	100
Static Display	N/A	50
Acceleration	N/A	100
Hill Climb	N/A	100
Handling	N/A	50
Emissions	200	250
Noise	100	150
Fuel Economy/Range	100	100
Cold Start	100	N/A
All Events	*500 points*	*1000 points*

9.2 Event Points

With the exception of the subjective design events (engineering design paper, oral design presentation, and static display), the team having the best score in each of the events will be awarded the maximum possible points (if they have also passed the event). Teams finishing behind those leaders will be awarded proportionally fewer points according to the scoring schemes that appear at the end of the following items. No negative points other than as a result of penalties will be awarded.

9.3 Penalties

Penalties will result from violating CSC2001 safety rules, performing prohibited maintenance on snowmobiles at any time after emission testing, drafting during the fuel economy/range event, or failing to meet competition deadlines.

9.4 Engineering Design Paper

9.4.1 Engineering Design Paper Description

This event requires the team to submit an engineering design paper describing the snowmobile conversion concept, design, and implementation. The paper should explain why modifications were performed and the results of testing and development. The paper must address the durability, practicality, and increased cost of any modifications. An absolute limit of **fifteen (15) pages** will be strictly enforced, except as noted below for papers submitted in alternative accessible formats.

FIVE hardcopies of the paper and one electronic copy (MSWord 97 format) are due by March 16, 2001. Late engineering design papers will receive 10 penalty points for each day that they are late, up to a maximum penalty equal to the team's score for this event. Hand written papers will not be accepted. Papers should be sent to: Dr. Lori M Fussell, 2570 Teton Pines Drive, Wilson, WY 83014. Papers must conform to the standard format for SAE technical papers. The format for SAE technical papers is available on-line through the SAE website at www.sae.org/products/papers/paperinfo/prepare.htm.

NOTE1: If notified by the CSC2001 Organizers, each team will also submit a hardcopy of the paper in alternative accessible *format (large print, for example). This paper will contain the same information as the 15 page paper. The final paper length will not be restricted in this case.*

9.4.2 Engineering Design Paper Scoring

This event is worth a maximum of 100 points. Engineering design paper judges will have a technical background. A sample engineering design paper judging form is located in the CSC2001 Rules Appendix.

9.5 Oral Design Presentation

9.5.1 Oral Design Presentation Description

A 10 minute oral presentation of the rationale and approach to the conversion is required, followed by a five-minute question and answer period. The presentation should state clearly how your modified snowmobile addresses the needs of snowmobilers (performance), environmentalists/park managers (noise and emissions), and snowmobile tour operators (cost, durability/re-sale value). Your presentation should convince people on all sides of the controversy surrounding snowmobiles in environmentally sensitive areas that your snowmobile is THE SOLUTION. The presentation will be judged on content, format, and delivery. All statements must be backed up with test results and science…this is a marketing delivery that must based in TRUTH.

Each team is required to submit either an electronic or hard copy of their oral design presentation to competition organizers at the completion of this event. Electronic copies may be submitted on 1.4” floppies, a zip disk, or a CD (no email). Teams failing to provide an electronic or hard copy of their oral presentation will receive 0 points for this event

9.5.2 Oral Design Presentation Scoring

This event is worth a maximum of 100 points. Oral design presentation judges will include snowmobilers, environmentalists, land managers, and engineers. A sample oral design presentation judging form is located in the CSC2001 Rules Appendix.

9.6 Acceleration Event

9.6.1 Acceleration Event Description

The acceleration event will be scored on the basis of elapsed time to 500 feet from a standing start. Student participants will drive their own snowmobiles in this event. The event will comprise the best of six runs (three in each direction) for which valid noise data are also obtained. If a noise measurement is invalid, so is the corresponding acceleration data.

All snowmobiles in the SAE CSC2001 are expected to complete this event with a time of less than 12 seconds. If a team's best time for this event is greater than 12 seconds, the team will fail this event and become ineligible to win the Quietest Snowmobile Award.

9.6.2 Acceleration Event Scoring

The winner of this event will receive 100 points. Teams failing this event will receive 0 points. Other scores will be determined using the following formula (Tyour = your best of six measured times, in seconds):

$$\text{Your Score} = \frac{\left(12/\text{Tyour}\right)^2 - 1}{\left(12/\text{Tmin}\right)^2 - 1} \times 100$$

9.7 Hill Climb

9.7.1 Hill Climb Description

The hill climb event will be scored based on maximum height reached and/or elapsed time to climb a course up Snow King Mountain. The course is approximately 3000 feet long, has an average grade of 19 degrees (39%), and a maximum grade of 30 degrees (60%). The event will comprise the better of two runs. Snowmobiles will be driven by professional snowmobile drivers, assigned randomly.

9.7.2 Hill Climb Scoring

Snowmobiles that do not reach the top of the course will be scored according to the following formula (Dyour = your highest distance on the hill, Dmax = highest distance by any snowmobile on the hill)

$$\text{Your Score} = (\text{Dyour/Dmax})^2 \times 50$$

Snowmobiles that reach the top of the course will be scored according to the following formula, with the winner of this event receiving 100 points. (Tyour = your best of two measured times, Tmax = longest time of the snowmobiles that succeed in climbing the hill, Tmin = shortest time of the snowmobiles that succeed in climbing the hill.)

$$\text{Your Score} = 50 + \left[\left(\frac{\left(\text{Tmax}/\text{Tyour}\right)^2 - 1}{\left(\text{Tmax}/\text{Tmin}\right)^2 - 1}\right) \times 50\right]$$

9.8 Emissions

9.8.1 Emission Event Description

Before being allowed to undergo CSC2001 emission testing, snowmobiles will be driven a minimum of 100 miles (to age catalysts).

Every attempt will be made to measure brake-specific emissions using laboratory-grade instrumentation and a snowmobile chassis dynamometer. If feasible, the 5-mode emission test cycle developed by the Southwest Research Institute (SwRI) will be used to test emissions. This cycle is shown on the next page for reference.

SwRI 5 Mode Snowmobile Engine Test Cycle

Mode	**1**	**2**	**3**	**4**	**5**
Speed, %	100	85	75	65	Idle
Torque, %	100	51	33	19	0
Wt. Factor, %	12	27	25	31	5

Test modes are run in order, from highest to lowest speed. One hundred percent engine speed is defined at the maximum steady engine speed in snowmobile operation. Torque values are specified as a percent of maximum (wide open throttle) torque observed at 100 percent speed in Mode 1.

If testing all five modes proves to be difficult, we may choose to test CSC2001 snowmobile emissions according to the following Three-mode snowmobile test cycle.

SwRI 3 Mode Snowmobile Engine Test Cycle

Mode	**1**	**2**	**3**
Speed, %	100	75	Idle
Torque, %	100	33	0
Wt. Factor, %	20	75	5

To assist with fast emission testing, teams will be required to show up at the competition with a standard fitting installed in their exhaust system. Details on this requirement will be available at a future date.

NOTE: The organizers of the CSC2001 are working very hard to develop the capability to test emissions as described above. If this is not possible, the organizers reserve the right to measure emissions in any other way possible. Hybrid electric snowmobiles will not have their emissions tested due the lack of time to develop a test procedure.

9.8.2 Emission Event Scoring

A snowmobile representative of a typical touring snowmobile in the Greater Yellowstone Area will be tested as part of the CSC2001 emission tests. The emission levels measured from this snowmobile will serve as baseline values.

Snowmobiles that have carbon monoxide (CO) emissions greater than 75% of the baseline's CO emissions ***or*** unburned hydrocarbon (UHC) plus oxides of nitrogen (NOx) emissions greater than 50% of the baseline snowmobile's UHC+NOx emissions will fail the event and receive 0 points. Points for snowmobiles that pass this event will be awarded according to the equation on the following page:

$$\text{Your Score} = 200 + 167\left(\frac{.5(HC+NOx)_{ref} - (HC+NOx)_{your}}{.5(HC+NOx)_{ref} - (HC+NOx)_{\min}}\right) + 83\left(\frac{.75CO_{ref} - CO_{your}}{.75CO_{ref} - CO_{\min}}\right)$$

9.9 Noise Event

9.9.1 Noise Event Description

Noise measurements of all snowmobiles will be taken according to SAE J192, the SAE recommended practice for measuring the exterior sound level from snowmobiles. This test procedure measures snowmobile noise while under wide open throttle acceleration, with measuring equipment located 50 feet from the road. Tests are performed on both sides of the snowmobile.

Test runs are repeated until three readings within a 2 dBA range per vehicle side have been obtained. The sound level for each side of the snowmobile is recorded as the average of all three readings, rounded to the nearest integer. The sound level used for scoring purposes will be that for the side of the snowmobile with the highest readings.

NOTE: Snowmobile acceleration will be measured during this event. However, if a noise measurement is deemed invalid, its corresponding acceleration measurement will also be invalid. The run will be repeated.

9.9.2 Noise Event Scoring

Snowmobiles louder than 74 dB measured on the A-weighted scale, 50 feet from the road will fail the noise event and receive 0 points. Snowmobiles 74 dB and quieter will be awarded points based on the following formula, with the quietest snowmobile receiving 250 points (dByour = your loudest dB measurement):

$$\text{Your Score} = 100 + \left[\frac{\left({}^{74}\!/_{\text{dByour}}\right)^2 - 1}{\left({}^{74}\!/_{\text{dBmin}}\right)^2 - 1}\right] \times 150$$

9.10 Cold Start Event

9.10.1 Cold Start Event Description

Snowmobiles will be cold-soaked overnight. Teams will have exactly one minute to start their snowmobile. The use of ether is not allowed.

9.10.2 Cold Start Event Scoring

Snowmobiles that do not start within 60 seconds will fail the cold start event and will receive 0 points. Snowmobiles that start within 60 seconds will receive 100 points.

9.11 Fuel Economy/Range Event

9.11.1 Fuel Economy/Range Event Description

All snowmobiles will complete a trip that is approximately 100 miles in length. Student participants will drive their own snowmobiles in this event. Participants are required to maintain a speed equal to the legal speed limit. The required speed may be lessened for safety in poor driving conditions. The legal speed limit is 45 miles/hour, with 35 miles/hour on some curves. Snowmobiles will leave will full tanks. The amount of fuel required to fill the tank upon return will be used to award points for this event. Drafting is strictly prohibited (see CSC2001 Rule 6.8). Infractions of the drafting rule can be reported by competing teams or by CSC2001 organizers.

9.11.2 Fuel Economy/Range Event Scoring

200 points will be awarded to the winner of this event. Teams that run out of fuel during this event will receive 0 points. Other scores will be determined by the following formula (G = number of gallons of fuel consumed):

$$\text{Your Score} = 100 + \left[\frac{\left({}^{\text{Gmax}}\!/_{\text{Gyour}} \right)^2 - 1}{\left({}^{\text{Gmax}}\!/_{\text{Gmin}} \right)^2 - 1} \times 100 \right]$$

NOTE: This event will be scored based on energy efficiency if any entries are hybrid electric snowmobiles or electric snowmobiles.

9.12 Handling/Driveability Event

9.12.1 Handling/Driveability Event Description

A minimum of five (5) different professional snowmobile drivers will ride snowmobiles around a mini snow cross course. Each driver will evaluate the snowmobile's handling and driveability. This is **NOT** a timed event. Scores will be based upon the drivers' o*pinions* only. Sample handling event judging forms are located in the CSC2001 Rules Appendix.

9.12.2 Handling/Driveability Event Scoring

Fifty (50) points will be awarded to the winner of this event. Other scores will be determined by the following formula (H = total of five drivers' scores):

$$\text{Your Score} = \frac{\left({}^{\text{Hyour}}\!/_{\text{Hmin}} \right)^2 - 1}{\left({}^{\text{Hmax}}\!/_{\text{Hmin}} \right)^2 - 1} \times 50$$

9.13 Static Display

9.13.1 Static Display Description

Each school will place their snowmobile on display at the World Championship Hill Climb. An outdoor, tented area will be provided for your snowmobile and display. The display is intended to serve as a marketing/promotional display that will encourage snowmobile outfitters to use your snowmobile as part of their rental fleet in Yellowstone National Park. Teams are encouraged to put up signs, hand out flyers, and use any other marketing techniques to attract attention to your prototype snowmobile. This is a judged event, with judging taking place on Friday afternoon. Sleds are required to remain on display until Saturday at 5:00 pm. Teams are encouraged to display their snowmobile through the end of the Hill Climb on Sunday afternoon.

9.13.2 Static Display Scoring

This event is worth a maximum of 50 points. Static display judges will have a technical background, be active snowmobilers, and/or be concerned about the impact of snowmobiles on the environment. A sample static display judging form is located in the CSC2001 Rules Appendix.

9.14 Technology Implementation Cost Assessment

9.14.1 Technology Implementation Cost Assessment Description

Each team is required to submit a Technology Implementation Cost Assessment (TICA) on their modified snowmobile. The TICA's purpose is to provide a standard method to compare the "manufacturer's cost" (cost TO the end snowmobile manufacturer) of each team's strategy for reducing emissions, noise, and fuel consumption. The TICA is not intended to evaluate the manufacturer's cost of "secondary" modifications such as suspension modifications or more comfortable seats.

It is the organizers' intent to make the completion of the TICA as simple as possible. Each team will be provided with an MSExcel97 spreadsheet that contains three separate worksheets:

1. The first worksheet, the Cost Index Reference, is a read-only worksheet that contains the specific nominal cost for individual components or information on how to determine the cost of individual components. Teams MUST SUBMIT copies of all manufacturer's quotes per 5000, manufacturer specification sheets, and retail receipts that are used to determine the cost of individual components on their snowmobile.
2. The second worksheet, the Cost Subtotals Worksheet, is where teams are required to input specific information on their entry. Only those cells requiring input may be modified. The rest of the spreadsheet is "protected".
3. The third worksheet, The Cost Totals Form, is a read-only worksheet that automatically calculates the final Technology Implementation Total Cost (TITC).

If at any time you have questions about the completion of the TICA spreadsheet, or if it does not adequately "evaluate" a system on your snowmobile, please contact Stephanie Cornelius at the address listed in CSC2001 Rule 5.1. Stephanie is very willing to assist teams with the completion of the TICA and would like it to provide "useful" information

One (1) hardcopy of the TICA, one (1) electronic copy (MSExcel97 format) of the TICA, and a copy of all supporting documentation, are due to Stephanie Cornelius (at the address listed in CSC2001 Rule 5.1) by March 16, 2001.

All teams will be required to update their TICA at the start of the CSC2001 and have their snowmobile inspected by Stephanie Cornelius to verify that their TICA is complete and accurate

9.14.2 Technology Implementation Cost Assessment "Scoring"

No points or penalties are associated with a teams final Technology Implementation Total Cost (TITC). TITCs will only be used to determine the winners of the awards for Most Practical Solution and Best Value. Teams not submitting a complete and accurate TICA will be ineligible to receive the awards for Most Practical Solution and Best Value.

10. ORGANIZER AUTHORITY

The organizers of the competition reserve the exclusive right to revise the schedule of the competition and/or to interpret the competition rules at any time and in any manner which is, in their sole judgment, required for efficient operation or safety of the competition.

APPENDIX

CSC2001 Engineering Design Paper Judging Form

Score the following categories, giving each points ranging from 0 (very bad) to the maximum points available for the category (excellent). The maximum points available for each category are listed in parenthesis.

When evaluating the papers, please keep in mind that the papers should be high-quality, technical papers that meet the rigorous standards required for publication in scholarly journals.

________ **CONTENT – PERFORMANCE (15):** Does the paper describe the challenges of maintaining/improving snowmobile performance (while reducing emissions and noise)? Does the paper describe the strategy the team selected to maintain/improve performance? Are adequate technical details given? Are adequate results given?

________ **CONTENT – EMISSION CONTROL (15):** Does the paper describe the challenges of improving snowmobile emissions? Does the paper describe the strategy team selected to improve emissions? Are adequate technical details given? Are adequate results given?

________ **CONTENT – NOISE (15):** Does the paper describe the challenges of reducing snowmobile noise? Does the paper describe the strategy team selected to reduce noise? Are adequate technical details given? Are adequate results given?

________ **CONTENT – FUEL ECONOMY (15):** Does the paper describe the challenges with improving snowmobile fuel economy? Does the paper describe the strategy team selected to improve fuel economy? Are adequate technical details given? Are adequate results given?

________ **CONTENT – COST/DURABILITY (15)** Does the paper describe how the modifications will effect the cost of the snowmobile? Will the snowmobile be cost effective? Does the paper describe how the modifications will effect the durability of the snowmobile? Will the snowmobile be durable?

________ **ORGANIZATION (10)** Was the paper format logical and organized? Did it contain an introduction/overview as well as conclusion/summary? Did the paper conform to the SAE standard format for technical papers?

________ **USE OF GRAPHICS – TABLES/GRAPHS/PICTURES (10) -** Were graphics used in the paper? Were they clearly explained in the text? Were they legible? Were they effective?

________ **REFERENCES (5)** Were references cited whenever appropriate? Were the references from high-quality sources?

________ **TOTAL = ENGINEERING DESIGN PAPER POINTS (100 Points maximum)**

COMMENTS: ____

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CSC2001 Oral Presentation Judging Form

Score the following categories on the basis of 0-12.5 points each according to the following scale (any number or fraction along this scale may be used).

0	=	inadequate or no attempt
2.5	=	attempted but below expectation
5	=	average or expected
7.5	=	above average but still lacking
10	=	excellent, meets intent
12.5	=	extraordinary, far exceeds expectations

________ **CONTENT (SNOWMOBILE OPERATOR PERSPECTIVE):** Does the presentation describe how the design will appeal to snowmobilers? Will the snowmobile maintain/improve performance and handling? Is enough detail given about how? Are there other factors that make this design more attractive to snowmobile operators?

________ **CONTENT (SNOWMOBILE OUTFITTER PERSPECTIVE):** Does the presentation describe how the design will meet the needs of snowmobile outfitters? Is the cost reasonable? Is the design durable and easy to maintain? Does the design allow operation by a novice snowmobiler? Is enough detail given about how these goals are met? Are there other factors that make this design more attractive to snowmobile outfitters?

________ **CONTENT (ENVIRONMENTAL PERSPECTIVE):** Does the presentation describe how the design will minimize the environmental impacts of the snowmobile? Are emissions reduced significantly? How much? Is the snowmobile quiet enough? How quiet? Is enough detail given about how these goals are met? Are there other factors that make this design more attractive from an environmental perspective?

________ **CONTENT (TEST RESULTS/SCIENCE):** Are test results given for all of the “claims” made about the modified snowmobile? Is the presentation based on “good science” (as opposed to a slick sales job)? Is data provided to support all conclusions?

CSC2001 Oral Presentation Judging Form (continued)

________ **ORGANIZATION:** Were the concepts presented in a logical order progressing from basic concept and showing how the engineering accomplished the concept? Was it clear to the audience what was to be presented and what was coming next? Were distinct introduction and overviews as well as summary and conclusions given?

________ **VISUAL AIDS:** Were visual aids used? Was the text readable? Were illustrations, graphs, and tables clearly explained? Were the visual aids effective?

________ **DELIVERY:** Did the presenter speak in a clear voice? Did the presenter show enthusiasm and promote confidence in the technical aspects? Did he/she maintain eye contact?

________ **QUESTIONS:** Did the answer illustrate that the team fully understood the question? Is there doubt that the team understood the answer? Did the team promote complete confidence in their response to the questions?

________ **TOTAL = PRESENTATION POINTS (100 Points maximum)**

COMMENTS:

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CSC2001 Static Display Judging Form

Score the following categories on the basis of 0-12.5 points each according to the following scale (any number or fraction along this scale may be used).

0	=	inadequate or no attempt
2.5	=	attempted but below expectation
5	=	average or expected
7.5	=	above average but still lacking
10	=	excellent, meets intent
12.5	=	extraordinary, far exceeds expectations

When evaluating the snowmobile and its static display, please keep in mind that the intent of this event is to encourage the student designs to be appealing to snowmobilers and snowmobile tour operators.

________ **AESTHETICS:** Does the snowmobile look attractive? Does it have a high performance appearance? Does have a quality appearance? Does it look fun to ride?

________ **STUDENTS:** Were the students present? Were they outgoing? Did they offer to tell you about their snowmobile? Did they seem knowledgeable? Were they able to answer your questions?

________ **DISPLAY/INFORMATION:** Are marketing-type materials provided (pamphlets, standing posters, etc.)? Are they informative? Would you be able to learn anything about the snowmobile if there weren't any students around?

________ **OVERALL IMPRESSION:** Were you convinced that the snowmobile would have enough power to be fun to ride on groomed trails? Were you convinced that a tour operator could use a fleet of these snowmobiles and still make money? Do you think this snowmobile could help protect access to pristine areas by being "clean and quiet"? Would you buy one?

CSC2001 Static Display Judging Form (Continued)

_______ **TOTAL = STATIC DISPLAY POINTS (50 Points maximum)**

COMMENTS:

CSC2001 Handling Event Judging Form

Score the following categories, giving each points ranging from 0 (very bad) to the maximum points available for the category (excellent). The maximum points available for each category are listed in parenthesis.

________ **CORNERING (5 points maximum):** Does the sled have solid steering? Is handling responsive? Do you have confidence that the sled will go where you point it?

________ **RIDE (5 points maximum):** Does the sled impress you as rideable? Could you ride this sled all day and be comfortable? Is sled ride consistent and smooth?

________ **ENGINE RESPONSE (7.5 points maximum):** Is the engine response quick and sure? Do RPM's increase/decrease quickly and smoothly? Is there any hesitation to increase RPM?

________ **CLUTCH/TRACTION (7.5 points maximum):** Does the clutch engage smoothly? Does the drive train put power to the snow well?

________ **BRAKING (7.5 points maximum):** Do the brakes engage properly? Are you confident the brakes will perform in an emergency situation?

________ **BALANCE (7.5 points maximum):** Is the sled balanced front to back and side to side? Is the sled nose heavy? Does is torque to the side?

________ **OVERALL PERFORMANCE (10 points maximum):** Do all parts of the performance seem to fit together? Are the controls simple and easy to operate? Are the handlebars, seat, and footrest comfortable and well laid out?

________ **TOTAL HANDLING EVENT POINTS (50 Points Maximum)**

COMMENTS:

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Appendix B

Detailed Emissions Report by Southwest Research Institute

"Emission Testing for the 2001 Clean Snowmobile Challenge"

SwRI 08.04294

EMISSION TESTING FOR THE 2001 CLEAN SNOWMOBILE CHALLENGE

By

Jeff J. White

FINAL REPORT

Prepared for

Institute of Science, Ecology and the Environment
2570 Teton Pines Drive
Wilson, Wyoming 83014

June 2001

June 25, 2001

TO: Institute of Science, Ecology and the Environment
2570 Teton Pines Drive
Wilson, WY 83014

ATTN: Dr. Lori Fussell
Executive Director

SUBJECT: Final Report, "Emission Testing for the 2001 Clean Snowmobile Challenge," SwRI Project 04294.

I. INTRODUCTION

The first SAE Clean Snowmobile Challenge (CSC) was held in Jackson Hole, Wyoming in late March of 2000. It drew public attention to environmental issues associated with recreational products such as snowmobiles, and encouraged development of novel solutions through this SAE-sponsored student competition. While much good information was obtained, one area needing improvement was emissions measurement. In 2000, snowmobile emissions were measured using a drive-by infrared-type device. While this provided a rough indication of emission levels, more accurate data was desired to better reflect progress in reducing emissions.

For this year's competition, Southwest Research Institute (SwRI) assembled the equipment necessary to provide brake-specific emissions measurement on-site. A truck-mounted mobile unit was outfitted with laboratory-grade instrumentation for measurement of HC, CO, NO_x, CO_2, and O_2. A snowmobile chassis dynamometer was used to load the engines. A modified version of the five mode snowmobile test cycle, as developed by SwRI for the International Snowmobile Manufacturers Association (ISMA), was used for testing.

Fourteen teams entered snowmobiles in the completion, employing a range of technologies, including both 2- and 4-stroke designs and aftertreatment. A detailed summary of competition emission results is included, along with a discussion of the effectiveness of various design approaches in reducing emissions.

II. THE CLEAN SNOWMOBILE CHALLENGE 2001

The SAE Clean Snowmobile Challenge 2001 was held in Jackson Hole, Wyoming from March 25-30, 2001. The first part of the competition, including the emissions testing, was conducted at Flagg Ranch Resort, which is north of Jackson, just south of Yellowstone National Park. Later parts of the competition were held in Grand Teton National Park, at Jackson Hole Mountain Resort, and at Snow King Resort.

Teams participating in CSC 2001 are listed in Table 1. Engine configurations, as run at the event, are also listed.

TABLE 1. SCHOOLS AND ENGINE DESCRIPTIONS

School	Engine
Clarkson University	Honda CBRT 929 EFI 4-stroke with catalyst
Colorado School of Mines	Honda CBR 600 F-4 carb. 4-stroke with TWC catalyst
Colorado State Univ. (CSU)	Supercharged reverse uniflow 600 cc Polaris 2-s with OX catalyst
Kettering University	3 cyl. 659 cc Daihatsu turbocharged EFI 4-stroke with TWC cat.
Michigan Technological Univ.	Honda VFR 791 cc EFI V-4 4-stroke with TWC catalyst
Minnesota State Univ. (Mankato)	500 cc liquid-cooled Polaris 2-stroke with TWC catalyst
Univ. at Buffalo (SUNY)	500 cc turbocharged EFI 4-stroke with TWC and OX catalysts
Univ. of Alaska, Fairbanks	3 cyl. 953 cc Suzuki turbocharged EFI 4-s with EGR and TWC
University of Alberta	Suzuki GSXR 600 cc EFI 4-stroke with TWC catalyst
University of Idaho	BMW K-75 750 cc 4-stroke with Bosch LE EFI and catalyst
University of Kansas	3 cyl. 929 cc Honda CBZ 4-stroke with OEM catalyst and sec. air
University of Waterloo	500 cc liquid-cooled Polaris carb. 2-stroke with dual-bed catalyst and secondary air injection
University of Wyoming	Kawasaki 617 cc 4-stroke engine with catalyst
Reference snowmobile	2001 Polaris Sport Touring, 550 cc 2-stroke

Rules of the emissions competition required teams to achieve a minimum of a 25% reduction in CO, and a 50% reduction in HC+NOx, as compared to current production snowmobiles. Failing either criterion would result in a zero score for the emissions event. To provide a reference point, a 2001 Polaris Sport Touring snowmobile equipped with a 550 cc 2-stroke engine was selected from the Flagg Ranch fleet of sleds. It was tested first to provide a reference, baseline emissions level for the competition.

III. TEST EQUIPMENT

A. Mobile Emissions Laboratory

A mobile laboratory (truck) was outfitted with laboratory-grade instrumentation for measurement of 2-stroke and 4-stroke engine HC, CO, CO_2, NO_x, and O_2 using raw exhaust gas sampling. See Figure 1. Major equipment required for the mobile laboratory emissions bench included:

- 2-stroke HC, HFID (SwRI design)
- 4-stroke HC, HFID (Rosemount 402)
- High CO, NDIR (Horiba)
- Low CO, NDIR (Rosemount 868)
- CO_2, NDIR (Rosemount 868)
- NOx, CLA (Rosemount 955)
- O_2 (Rosemount CM1EA)
- Raw exhaust sampling system with heated (375°F) sample lines
- Chart recorder
- Calibration gases, NIST traceable

FIGURE 1. EMISSIONS BENCH

B. Dynojet Dynamometer

A Dynojet snowmobile chassis dynamometer was used to load snowmobile engines during emissions testing. See Figure 2. The dynamometer uses air-cooled eddy current absorbers, and can achieve a maximum load of 867 lb-ft. The dyno can perform closed-loop control on mph (track speed) or torque, or on engine rpm. A dedicated computer provides dynamometer control and data acquisition. Readouts are available for engine speed, sled speed, and torque.

FIGURE 2. DYNOJET DYNAMOMETER

Prior to testing, each snowmobile's stock suspension was removed and replaced with an adjustable dynamometer carriage that provided connection to the dyno from the rear belt sprocket, plus a means of adjusting belt tension. This is shown in Figure 3. Two dyno carriages were used at the event so that the next sled to be tested could be fitted with a carriage while the preceding sled was being tested.

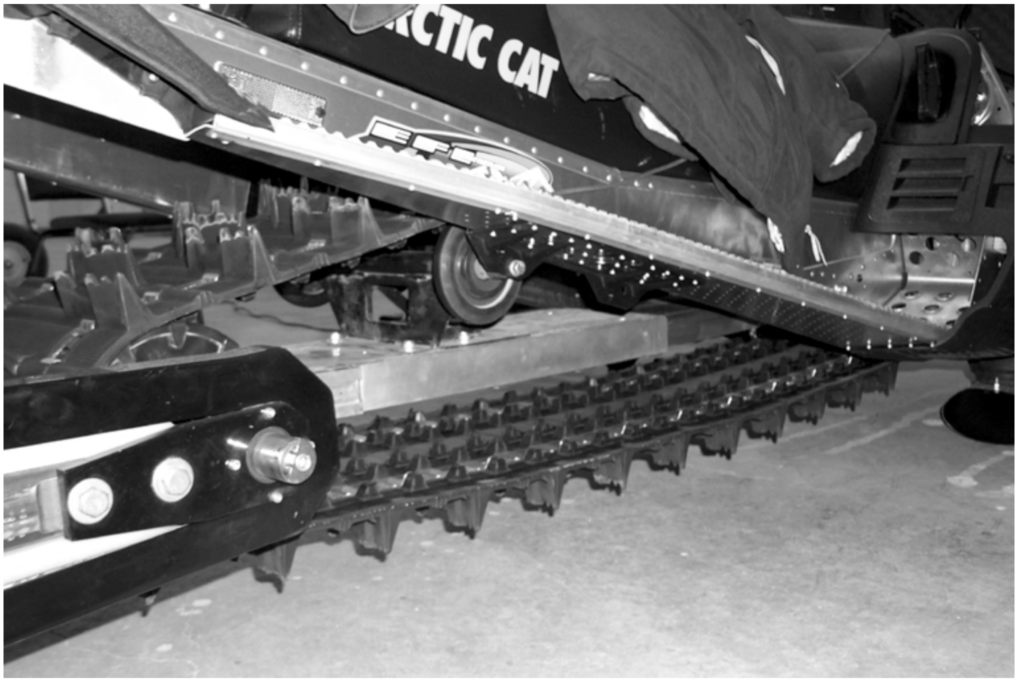

FIGURE 3. DYNAMOMETER CARRIAGE

C. Exhaust Gas Sampling Probe

Each sled in the competition was required to be fitted with an exhaust gas sampling probe, in accordance with probe design and installation specifications, as described below.

Sample probe. (1) The sample probe shall be a straight, closed end, stainless steel, multi-hole probe made from ¼ in. OD stainless steel tubing. The wall thickness of the probe shall not be greater than 0.10 cm. (2) The probe shall have nine 1/16 in. holes. The spacing of the radial planes for each hole in the probe must be such that they cover approximately equal cross-sectional areas of the exhaust duct. The nine holes shall be drilled in a spiral pattern with an angular spacing between adjacent holes of approximately 120 degrees. This results in a spiral pattern with three triads of holes aligned along the length of the probe.

Probes were installed in engine exhaust systems using stainless-steel Swagelok fittings, in accordance with the following requirements:

1. For systems without aftertreatment, the probe must be placed after the point at which the exhaust from all cylinders is well

mixed, a minimum of five pipe diameters downstream of the last 'Y' connection.

2. For systems with air injection or aftertreatment, the probe must be placed a minimum of five pipe diameters downstream of the converter outlet.

3. For all systems, the probe must be placed a minimum of 12 in. upstream of the end of the exhaust pipe.

D. Fuel Flow Measurement

Accurate fuel flow data are required to make brake-specific emissions measurements. Three different fuel flow measurement techniques were provided to accommodate the range of sled fuel supply systems. For sleds with a single fuel supply line to the engine (no return line), we used a small fuel flow meter (Max, model 213-186) that was inserted into the fuel line. For sleds with a separate return line, fuel consumption was measured gravimetrically. Teams with this type of fuel system were required to provide a second sled fuel tank/pump system that could be mounted on a digital scale. Valves were installed in the sled's fuel system so it could be switched between the on-board and the external fuel supply tanks. We also provided a day tank system which could be used for sleds with a fuel return line.

E. Supplemental Engine Cooling System

Supplemental cooling is required for snowmobile engine operation on either a stand or a chassis-type dynamometer. Fan-cooled engines were tested with two supplemental cooling fans directed onto the engine with the cover open. For liquid-cooled engines, we constructed an external heat exchanger system consisting of a small automotive radiator with an electric fan. See Figure 4. Teams made provisions to hook up to this external system for operation on the dynamometer. Liquid-cooled sleds were configured with supply and return lines available in their cooling systems with 1 in. male hose-barbed fittings for connection to the external system. Shutoff ball valves were placed immediately before the hose fittings to minimize loss of coolant when switching over. The external system was filled with Arctic Cat premixed coolant.

FIGURE 4. SUPPLEMENTAL COOLING

After connection to the external cooling system, sleds were run for several minutes to purge all air bubbles from the system. The radiator was then topped up and the radiator pressure cap was installed. Engine water temperature control was provided by the engine thermostat.

IV. TEST PROCEDURE

To facilitate a comparison of CSC 2001 emission data with previously generated laboratory data, we planned to use the five-mode snowmobile test cycle, as developed by SwRI for the International Snowmobile Manufacturers Association (ISMA). This cycle is shown in Table 2 for reference.

TABLE 2. ISMA/SWRI SNOWMOBILE ENGINE TEST CYCLE

Mode	1	2	3	4	5
Speed, %	100	85	75	65	Idle
Torque, %	100	51	33	19	0
Wt. Factor, %	12	27	25	31	5

Test modes are run in order, from highest to lowest speed. One hundred percent engine speed is defined as the maximum steady engine speed in snowmobile operation. Torque values are specified as a percent of the maximum (WOT) torque observed at 100 percent speed in mode 1.

While experiments with the baseline 2-stroke sled showed good control under most conditions, mode 4 was problematic due to the low applied load and variability in snowmobile clutch engagement. The test cycle was modified by eliminating mode 4, and proportionally reassigning its mode weight to the remaining modes. The modified cycle is shown in Table 3. Teams determined maximum steady speeds (sled mph and engine rpm) at WOT after arriving at Flagg Ranch. These values were used to set up test modes on the dynamometer for individual sleds.

TABLE 3. MODIFIED SNOWMOBILE ENGINE TEST CYCLE

Mode	1	2	3	4
Speed, %	100	85	75	Idle
Torque, %	100	51	33	0
Wt. Factor, %	18	39	36	7

V. FUELS AND LUBRICANTS

Teams were allowed a choice of three fuels: premium gasoline, premium E10 (10% ethanol), or regular E10 (10% ethanol). Samples of the three fuels were analyzed, and results are summarized in Table 4.

TABLE 4. FUELS ANALYSES

	Regular E10	Premium	Premium E10
Specific Gravity at 50F, g/ml	0.740	0.717	0.719
Specific Gravity at 30F, g/ml	0.748	0.726	not determined
Carbon, mass %	83.10	84.83	81.96
Hydrogen, mass %	13.15	14.49	14.48
Oxygen, mass %	3.75	n/a	3.56

Fuels used during the competition are identified in the summary table of emission results. Teams were free to use their choice of lubricant.

VI. EMISSION RESULTS

Snowmobiles were emissions tested in a maintenance shed at Flagg Ranch. After replacing the sled's track with a dynamometer carriage, it was installed on the snowmobile chassis dynamometer and prepared for testing. Fuel flow measurement equipment was connected to the sled's fuel system, and the supplemental cooling system was connected for liquid-cooled sleds. Supplemental blowers were positioned to direct air into the open engine compartment. The heated sample line was connected to the probe to extract a sample of raw exhaust gas.

Sleds were first warmed up to normal operating temperature, and then run at WOT at the declared maximum sled speed. Dynamometer load was then adjusted to obtain the team's declared maximum engine speed to establish Mode 1 conditions. Test modes were then run in order, from Mode 1 to 4. Emission results were calculated following procedures specified for nonroad spark-ignited engines (40 CFR Part 90).

Two sleds were unable to complete emissions testing. CSU's engine suffered a mechanical failure, and Michigan Tech's drive chain failed. Teams from Alaska and Kansas were unable to get their engines running properly in time for emissions testing. Emission results for the nine teams completing testing, plus the reference Polaris sled, are summarized in Table 5. Emission reductions achieved by the student sleds, as compared to the reference sled, are summarized in Table 6. Detailed modal results for each sled, including carbon balance calculated air/fuel ratios, are attached.

TABLE 5. EMISSION RESULTS

Sled	Engine Type	Rated Speed rpm	Track Power kW	Fuel	Weighted Emissions, g/kW-hr			
					HC	CO	NO_x	HC+ NO_x
Flagg Ranch, Baseline	2-Stroke	7,200	9.73	Reg. E10	177.9	1524	2.32	180.2
Clarkson Univ.	4-Stroke	10,000	39.67	Premium	19.1	736	0.05	19.2
Colorado Mines	4-Stroke	9,000	3.14	Prem. E10	30.8	948	3.63	34.4
Kettering Univ.	4-Stroke	7,100	28.22	Reg. E10	4.2	323	0.85	5.1
Minn. State, Mankato	2-Stroke	7,800	34.84	Prem. E10	35.4	387	2.16	37.6
Univ. at Buffalo, SUNY	4-Stroke	6,100	7.13	Premium	5.6	267	0.22	5.8
Univ. of Alberta	4-Stroke	8,200	20.13	Premium	58.5	840	1.13	59.6
Univ. of Idaho	4-Stroke	7,200	13.12	Reg. E10	28.3	625	1.40	29.7
Univ. of Waterloo	2-Stroke	7,000	18.76	Prem. E10	65.9	617	0.63	66.5
Univ. of Wyoming	4-Stroke	2,500	1.48	Prem. E10	70.2	599	22.88	93.1

TABLE 6. EMISSION REDUCTIONS COMPARED TO BASELINE SLED

Sled	CO, % Reduction	HC, % Reduction	NOx, % Reduction	HC+NOx, % Reduction
Clarkson Univ.	52	89	98	89
Colorado Mines	38	83	-56*	81
Kettering Univ.	79	98	63	97
Minn. State, Mankato	75	80	7	79
Univ. at Buffalo, SUNY	82	97	91	97
Univ. of Alberta	45	67	51	67
Univ. of Idaho	59	84	40	84
Univ. of Waterloo	60	63	73	63
Univ. of Wyoming	61	61	-886	48
* Negative numbers indicate an increase in emissions				

The Flagg Ranch sled CO value is higher than those observed with laboratory-tested snowmobile engines, likely due to the lower barometric pressure at Flagg Ranch (typically 23-24 in. Hg), and the use of a one size larger jet for improved operation and durability.

Two 2-stroke powered sleds from Waterloo and Mankato completed emission testing. Both maintained reasonably good power while also significantly reducing emissions, compared to the reference sled. Both teams employed slightly leaner calibrations and catalysts to reduce HC and CO emissions.

The seven 4-stroke engines tested came from a variety of sources ranging from motorcycle engines (Mines, Idaho, Alberta, and Clarkson) to automotive engines (Kettering), to ATV engines (Buffalo and Wyoming). Sled emission results were affected by a number of factors. Since emissions were determined on a brake-specific (work) basis, power level is significant. Sleds from Mines and Wyoming were able to deliver only limited amounts of power to the dynamometer. This illustrates the importance of proper clutching, since the engines were clearly able to produce more power than their drivetrains could deliver to their belts. Thus, lower power levels, all other things being equal, will result in higher brake-specific emission levels.

It should be emphasized that power levels reported in Table 5 are indicated (uncorrected) power, as measured from the <u>sled track</u>. Laboratory snowmobile emissions are determined using an engine dynamometer with power measured at the <u>engine crankshaft</u>. Since the typical snowmobile loses on the order of 50 percent of its power in track and drivetrain losses, chassis dynamometer measured brake-specific emission levels will be significantly higher than engine dynamometer measured emissions.

Another major factor influencing 4-stroke engine results was air-fuel calibration. While 4-strokes avoid the scavenging losses of the 2-stroke design, most engines were still operating rich at one or more modes, resulting in relatively high CO emissions. The Wyoming sled, on the other hand, ran very lean at Modes 2 and 3, which created high NO_x levels.

The two snowmobiles with the best emissions were better calibrated and had better emission reduction technology. Buffalo's sled ran at or near stoichiometric, except during Mode 3 which was rich. This, coupled with a dual-brick TWC+OX catalyst system, provided the lowest overall emissions, narrowly beating Kettering who placed second in the emissions event. The Kettering sled employed a 3-cylinder Daihatsu automotive engine, complete with factory calibration and catalyst system, as designed for Japanese automotive emission standards. This "drop-in" solution performed very well, although it ran very rich at Mode 1 (WOT), as is typical for an automotive calibration.

Emissions from all sleds could have been further improved if more time had been available for engine and drivetrain calibration. Results are still very impressive given the limited time and budget available to these teams.

VII. SUMMARY AND CONCLUSIONS

Fourteen student teams entered snowmobiles in the 2001 SAE Clean Snowmobile Challenge. Competition objectives called for reducing noise and exhaust emissions while maintaining respectable performance and handling characteristics. Equipment was assembled on-site at Jackson Hole to provide for brake-specific emissions measurement using a snowmobile chassis dynamometer and a modified version of the ISMA snowmobile engine test cycle.

Both 2- and 4-stroke solutions were entered in the competition; many incorporated catalytic aftertreatment in their designs. The Waterloo 2-stroke sled that placed first overall in the competition was able to reduce its HC+NOx emissions to 66.5 g/kW-h, and its CO emissions to 617 g/kW-h. The sled with the lowest emissions (Buffalo), employed a 4-stroke engine with both three-way and oxidation catalysts. It achieved emission levels of 5.8 g/kW-h HC+NOx and 267 g/kW-h CO, which represents a 97% and an 82% reduction respectively, from the reference sled.

While none of these designs constitute a production-ready solution, they clearly show that there are alternatives to the conventional, high-emitting 2-stroke, which can provide acceptable performance in a touring sled.

Prepared by:	Approved by:
Jeff J. White Manager, Certification, Audit, and Compliance Department of Emissions Research	Charles T. Hare Director Department of Emissions Research

DEPARTMENT OF EMISSIONS RESEARCH
AUTOMOTIVE PRODUCTS AND EMISSIONS RESEARCH DIVISION

ATTACHMENTS

SNOWMOBILE MODAL EMISSION RESULTS

FLAGG RANCH - BASELINE

Test Number: Flagg
Date: 3/24/01
Time: 04:00 PM
Engine: 2-Stroke
Fuel: Regular E10
Displacement: 550 cc
Rated Speed: 7200 rpm
Full Throttle Power: 9.73 kW
Weighted Ave. Measured Power: 4.00 kW

Mode	Speed % of Rated	Torque % of Mode 1 Maximum	Mass Emissions, g/hr			Mode Weight Factor	Modal Brake Specific Emissions, g/kWh		
			HC	CO	NOx		HC	CO	NOx
1	100	100	1379	15101	11	0.18	141.7	1552	1.17
2	85	51	776	7174	13	0.39	185.1	1711	3.06
3	75	33	338	1453	6.0	0.36	199.5	858	3.56
4	IDLE	0	548	746.6	0.6	0.07			

	g/hr		
Weighted Hourly Mass Emissions	711	6091	9
	g/kWhr		
Weighted Brake Specific Mass Emissions	177.9	1524	2.32

Engine:2-Stroke **Run #:Flagg**	**Average Mode 1**	**Average Mode 2**	**Average Mode 3**	**Average Mode 4**
TRACK SPEED [mph]:	70	50	32	0
DYNO TORQUE [lb-ft]:	32	20	12	0.0
DYNO SPEED [rpm]:	2118	1513	968	0
DYNO POWER [kW]	9.73	4.19	1.69	0.0
FUEL FLOW [g/hr]:	12967	7728	3493	1310
FUEL FLOW [lb/hr]:	29.7	17.7	8.0	3.00
NOx HUMID. ADJ. FACTOR [KH]:	1.00	1.00	1.00	1.00
DRY-WET CONV. FACTOR [K]:	0.91	0.90	0.89	0.94
AIR/FUEL RATIO:	9.3	10.6	13.3	12.5
CO, %[wet]:	10.09	7.37	2.88	4.08
CO2, %[wet]:	5.54	7.05	9.74	4.33
HC, ppmC[wet]:	18600	16100	13500	60500
NOx, ppm[wet]:	46	80	72.7	18.8
O2, %[wet]	3.04	3.14	4.61	9.78
F Factor	1.218	1.218	1.218	1.218
BSFC, g/kW-hr	1332	1843	2064	

COLORADO MINES

Test Number: Colorado Mines
Date: 3/25/01
Time: 04:45 PM
Engine: 4-Stroke
Fuel: Premium E10
Displacement: 600 cc
Rated Speed: 9000 rpm
Full Throttle Power: 3.14 kW
Weighted Ave. Measured Power: 1.26 kW

Mode	Speed % of Rated	Torque % of Mode 1 Maximum	Mass Emissions, g/hr			Mode Weight Factor	Modal Brake Specific Emissions, g/kWh		
			HC	CO	NOx		HC	CO	NOx
1	100	100	112	3944	14	0.18	35.7	1257	4.52
2	85	51	24	582	3	0.39	19.6	466	2.15
3	75	33	21	621	2.7	0.36	37.5	1093	4.70
4	IDLE	0	18	441.7	0.0	0.07			

Weighted Hourly Mass Emissions	**g/hr**		
	39	1191	5
Weighted Brake Specific Mass Emissions	**g/kWhr**		
	30.8	948	3.63

Engine: 4-Stroke Run #: Colorado Mines	**Average Mode 1**	**Average Mode 2**	**Average Mode 3**	**Average Mode 4**
TRACK SPEED [mph]:	40	25	15	0
DYNO TORQUE [lb-ft]:	18	12	9	0.0
DYNO SPEED [rpm]:	1210	756	454	0
DYNO POWER [kW]	3.1	1.2	0.6	0.0
FUEL FLOW [g/hr]:	7794	4078	3580	680
FUEL FLOW [lb/hr]:	17.9	9.3	8.2	1.56
NOx HUMID. ADJ. FACTOR [KH]:	0.858	0.86	0.86	0.86
DRY-WET CONV. FACTOR [K]:	0.880	0.88	0.88	0.88
AIR/FUEL RATIO:	12.5	14.5	14.3	11.7
CO, %[wet]:	3.66	0.94	1.15	4.91
CO2, %[wet]:	10.74	12.30	12.18	9.93
HC, ppmC[wet]:	2100	800	800	4100
NOx, ppm[wet]:	93	31	35.2	1.8
O2, %[wet]	0.04	0.15	1.13	0.22
F Factor	1.219	1.219	1.219	1.219
BSFC, g/kW-hr	2485	3263	6297	

WATERLOO

Test Number: Waterloo
Engine: 2-Stroke
Rated Speed: 7000 rpm

Date: 3/26/01
Fuel: Premium E10

Time: 05:00 PM
Displacement: 500 cc
Full Throttle Power: 18.75 kW
Weighted Ave. Measured Power: 7.40 kW

Mode	Speed % of Rated	Torque % of Mode 1 Maximum	Mass Emissions, g/hr			Mode Weight Factor	Modal Brake Specific Emissions, g/kWh		
			HC	CO	NOx		HC	CO	NOx
1	100	100	1671	17539	6	0.18	89.1	935	0.31
2	85	51	365	3408	4	0.39	50.0	466	0.51
3	75	33	123	169	6.1	0.36	37.7	52	1.86
4	IDLE	0	2	260.2	0.1	0.07			

Weighted Hourly Mass Emissions	**g/hr**		
	488	4565	5
Weighted Brake Specific Mass Emissions	**g/kWhr**		
	65.9	617	0.63

Engine: 2-Stroke Run #: Waterloo	Average Mode 1	Average Mode 2	Average Mode 3	Average Mode 4
TRACK SPEED [mph]:	70	46	32	0
DYNO TORQUE [lb-ft]:	62	37	24	0.0
DYNO SPEED [rpm]:	2118	1392	968	0
DYNO POWER [kW]	18.8	7.3	3.3	0.0
FUEL FLOW [g/hr]:	14844	5676	3536	2008
FUEL FLOW [lb/hr]:	34.0	13.0	8.1	4.60
NOx HUMID. ADJ. FACTOR [KH]:	1.00	1.00	1.00	1.00
DRY-WET CONV. FACTOR [K]:	0.91	0.89	0.89	0.88
AIR/FUEL RATIO:	9.1	12.5	16.3	14.8
CO, %[wet]:	10.35	4.30	0.29	0.84
CO2, %[wet]:	5.34	9.22	11.34	12.21
HC, ppmC[wet]:	19900	9300	4200	100
NOx, ppm[wet]:	21	29	62.5	2.6
O2, %[wet]	2.23	1.43	3.39	0.44
F Factor	1.206	1.206	1.206	1.206
BSFC, g/kW-hr	792	776	1080	

MANKATO

Test Number: Mankato
Date: 3/27/01
Time: 10:30 PM
Engine: 2-Stroke
Fuel: Premium E10
Displacement: 500 cc
Rated Speed: 7800 rpm
Full Throttle Power: 34.84 kW
Weighted Ave. Measured Power: 14.2 kW

Mode	Speed % of Rated	Torque % of Mode 1 Maximum	Mass Emissions, g/hr			Mode Weight Factor	Modal Brake Specific Emissions, g/kWh		
			HC	CO	NOx		HC	CO	NOx
1	100	100	2313	24455	18	0.18	66.4	702	0.52
2	85	51	190	2316	29	0.39	13.8	168	2.10
3	75	33	33	150	44.9	0.36	4.7	21	6.30
4	IDLE	0	13	2135.2	0.0	0.07			

Weighted Hourly Mass Emissions	**g/hr**		
	504	5509	31
Weighted. Brake Specific Mass Emissions	**g/kWhr**		
	35.4	387	2.16

Engine: 2-Stroke **Run #: Mankato**	**Average Mode 1**	**Average Mode 2**	**Average Mode 3**	**Average Mode 4**
TRACK SPEED [mph]:	75	52	42	0
DYNO TORQUE [lb-ft]:	108	62	40	0.0
DYNO SPEED [rpm]:	2269	1573	1271	0
DYNO POWER [kW]	34.8	13.8	7.1	0.0
FUEL FLOW [g/hr]:	23226	8033	5108	2576
FUEL FLOW [lb/hr]:	53.2	18.4	11.7	5.90
NOx HUMID. ADJ. FACTOR [KH]:	1.00	1.00	1.00	1.00
DRY-WET CONV. FACTOR [K]:	0.90	0.88	0.89	0.88
AIR/FUEL RATIO:	9.1	13.5	16.1	11.2
CO, %[wet]:	9.32	1.99	0.18	6.36
CO2, %[wet]:	6.77	11.62	11.95	9.05
HC, ppmC[wet]:	17800	3300	800	800
NOx, ppm[wet]:	42	152	323.4	0.9
O2, %[wet]	0.60	0.19	2.39	0.02
F Factor	1.193	1.193	1.193	1.193
BSFC, g/kW-hr	667	582	717	

BUFFALO

Test Number: Buffalo
Engine: 4-Stroke
Rated Speed: 6100 rpm

Date: 3/27/01
Fuel: Premium

Time: 09:30 PM
Displacement: 498 cc
Full Throttle Power: 7.13 kW
Weighted Ave. Measured Power: 2.8 kW

Mode	Speed % of Rated	Torque % of Mode 1 Maximum	Mass Emissions, g/hr			Mode Weight Factor	Modal Brake Specific Emissions, g/kWh		
			HC	CO	NOx		HC	CO	NOx
1	100	100	8	159	3	0.18	1.1	22	0.42
2	85	51	12	504	0	0.39	4.4	180	0.04
3	75	33	26	1455	0.1	0.36	20.9	1164	0.08
4	IDLE	0	5	93.1	0.0	0.07			

Weighted Hourly Mass Emissions	g/hr		
	16	755	1
Weighted Brake Specific Mass Emissions	g/kWhr		
	5.6	267	0.22

Engine: 4-Stroke Run #: Buffalo	**Average Mode 1**	**Average Mode 2**	**Average Mode 3**	**Average Mode 4**
TRACK SPEED [mph]:	55	35	22	0
DYNO TORQUE [lb-ft]:	30	19	13	0.0
DYNO SPEED [rpm]:	1664	1059	666	0
DYNO POWER [kW]	7.1	2.8	1.2	0.0
FUEL FLOW [g/hr]:	5154	2734	2008	350
FUEL FLOW [lb/hr]:	11.4	6.0	4.4	0.77
NOx HUMID. ADJ. FACTOR [KH]:	0.796	0.80	0.80	0.80
DRY-WET CONV. FACTOR [K]:	0.879	0.88	0.89	0.89
AIR/FUEL RATIO:	14.8	14.5	12.1	14.7
CO, %[wet]:	0.20	1.21	5.25	1.70
CO2, %[wet]:	12.99	11.98	9.18	11.04
HC, ppmC[wet]:	200	600	1900	1800
NOx, ppm[wet]:	29	2	2.7	0.9
O2, %[wet]	0.31	0.72	2.21	1.53
F Factor	1.188	1.188	1.188	1.188
BSFC, g/kW-hr	723	975	1607	

IDAHO

Test Number: Idaho
Date: 3/25/01
Time: 11:55 PM
Engine: 4-Stroke
Fuel: Regular E10
Displacement: 750 cc
Rated Speed: 7200 rpm
Full Throttle Power: 13.12 kW
Weighted Ave. Measured Power: 4.7 kW

Mode	Speed % of Rated	Torque % of Mode 1 Maximum	Mass Emissions, g/hr			Mode Weight Factor	Modal Brake Specific Emissions, g/kWh		
			HC	CO	NOx		HC	CO	NOx
1	100	100	171	7427	15	0.18	13.0	566	1.16
2	85	51	152	2526	5	0.39	35.3	588	1.20
3	75	33	109	1497	5.0	0.36	63.0	868	2.88
4	IDLE	0	42	697.0	0.1	0.07			

Weighted Hourly Mass Emissions	g/hr		
	132	2910	7
Weighted Brake Specific Mass Emissions	g/kWhr		
	28.3	625	1.40

Engine: 4-Stroke **Run #: Idaho**	**Average Mode 1**	**Average Mode 2**	**Average Mode 3**	**Average Mode 4**
TRACK SPEED [mph]:	60	36	21	0
DYNO TORQUE [lb-ft]:	51	28	19	0.0
DYNO SPEED [rpm]:	1815	1089	635	0
DYNO POWER [kW]	13.1	4.3	1.7	0.0
FUEL FLOW [g/hr]:	10347	5938	3842	830
FUEL FLOW [lb/hr]:	23.7	13.6	8.8	1.90
NOx HUMID. ADJ. FACTOR [KH]:	0.870	0.87	0.87	0.87
DRY-WET CONV. FACTOR [K]:	0.879	0.88	0.88	0.88
AIR/FUEL RATIO:	11.1	12.4	12.4	10.2
CO, %[wet]:	5.60	3.13	2.87	6.98
CO2, %[wet]:	9.89	11.35	11.56	8.95
HC, ppmC[wet]:	2600	3800	4200	8400
NOx, ppm[wet]:	80	45	66.6	4.4
O2, %[wet]	0.04	0.06	0.95	0.40
F Factor	1.216	1.216	1.216	1.216
BSFC, g/kW-hr	789	1382	2228	

ALBERTA

Test Number: Alberta
Engine: 4-Stroke
Rated Speed: 8200 rpm

Date: 3/26/01
Fuel: Premium

Time: 08:00 PM
Displacement: 600 cc
Full Throttle Power: 20.13 kW
Weighted Ave. Measured Power: 8.05 kW

Mode	Speed % of Rated	Torque % of Mode 1 Maximum	Mass Emissions, g/hr			Mode Weight Factor	Modal Brake Specific Emissions, g/kWh		
			HC	CO	NOx		HC	CO	NOx
1	100	100	777	8327	27	0.18	38.6	414	1.35
2	85	51	343	7528	9	0.39	45.5	998	1.19
3	75	33	523	6253	1.9	0.36	126.5	1512	0.45
4	IDLE	0	136	1134.2	0.4	0.07			

Weighted Hourly Mass Emissions	**g/hr**		
	471	6765	9
Weighted Brake Specific Mass Emissions	**g/kWhr**		
	58.5	840	1.13

Engine: 4-Stroke **Run #: Alberta**	**Average Mode 1**	**Average Mode 2**	**Average Mode 3**	**Average Mode 4**
TRACK SPEED [mph]:	55	36	30	0
DYNO TORQUE [lb-ft]:	85	49	32	0.0
DYNO SPEED [rpm]:	1664	1089	908	0
DYNO POWER [kW]	20.1	7.5	4.1	0.0
FUEL FLOW [g/hr]:	11567	7258	5806	2449
FUEL FLOW [lb/hr]:	25.5	16.0	12.8	5.40
NOx HUMID. ADJ. FACTOR [KH]:	0.808	0.81	0.81	0.81
DRY-WET CONV. FACTOR [K]:	0.883	0.89	0.89	0.89
AIR/FUEL RATIO:	10.6	9.3	8.6	13.3
CO, %[wet]:	5.84	9.03	10.01	3.18
CO2, %[wet]:	9.43	7.71	7.06	9.91
HC, ppmC[wet]:	11000	8300	16900	7700
NOx, ppm[wet]:	143	81	22.3	8.9
O2, %[wet]	0.02	0.02	0.96	1.51
F Factor	1.205	1.205	1.205	1.205
BSFC, g/kW-hr	575	962	1404	

CLARKSON

Test Number: Clarkson
Engine: 4-Stroke
Rated Speed: 10,000 rpm

Date: 3/26/01
Fuel: Premium

Time: 06:00 PM
Displacement: 929 cc
Full Throttle Power: 39.67 kW
Weighted Ave. Measured Power: 15.2 kW

Mode	Speed % of Rated	Torque % of Mode 1 Maximum	Mass Emissions, g/hr			Mode Weight Factor	Modal Brake Specific Emissions, g/kWh		
			HC	CO	NOx		HC	CO	NOx
1	100	100	367	16573	1	0.18	9.2	418	0.03
2	85	51	343	10109	1	0.39	23.1	682	0.05
3	75	33	253	11858	0.6	0.36	39.9	1865	0.09
4	IDLE	0	1	2.3	0.0	0.07			

Weighted Hourly Mass Emissions	**g/hr**		
	291	11,195	1
Weighted Brake Specific Mass Emissions	**g/kWhr**		
	19.1	736	0.05

Engine: 4-Stroke Run #: Clarkson	**Average Mode 1**	**Average Mode 2**	**Average Mode 3**	**Average Mode 4**
TRACK SPEED [mph]:	75	49	34	0
DYNO TORQUE [lb-ft]:	123	70	44	0.0
DYNO SPEED [rpm]:	2269	1482	1029	0
DYNO POWER [kW]	39.7	14.8	6.4	0.0
FUEL FLOW [g/hr]:	18576	10800	11265	781
FUEL FLOW [lb/hr]:	41.0	23.8	24.8	1.72
NOx HUMID. ADJ. FACTOR [KH]:	0.839	0.84	0.84	0.84
DRY-WET CONV. FACTOR [K]:	0.877	0.88	0.88	0.89
AIR/FUEL RATIO:	9.7	9.2	8.6	16.2
CO, %[wet]:	7.61	8.33	9.73	0.02
CO2, %[wet]:	9.27	9.07	8.51	12.17
HC, ppmC[wet]:	3400	5700	4200	100
NOx, ppm[wet]:	4	4	3.5	0.4
O2, %[wet]	0.02	0.02	0.90	0.22
F Factor	1.208	1.208	1.208	1.208
BSFC, g/kW-hr	468	729	1772	

KETTERING

Test Number: Kettering
Engine: 4-Stroke
Rated Speed: 7100 rpm

Date: 3/26/01
Fuel: Regular E10

Time: 11:15 PM
Displacement: 659 cc
Full Throttle Power: 28.22 kW
Weighted Ave. Measured Power: 12.4 kW

Mode	Speed % of Rated	Torque % of Mode 1 Maximum	Mass Emissions, g/hr			Mode Weight Factor	Modal Brake Specific Emissions, g/kWh		
			HC	CO	NOx		HC	CO	NOx
1	100	100	185	18195	10	0.18	6.6	645	0.35
2	85	51	42	1852	21	0.39	3.3	145	1.61
3	75	33	7	53	2.0	0.36	1.0	8	0.31
4	IDLE	0	1	2.0	0.0	0.07			

	g/hr		
Weighted Hourly Mass Emissions	52	4017	11
	g/kWhr		
Weighted Brake Specific Mass Emissions	4.2	323	0.85

Engine: 4-Stroke Run #: Kettering	**Average Mode 1**	**Average Mode 2**	**Average Mode 3**	**Average Mode 4**
TRACK SPEED [mph]:	71	55	44	0
DYNO TORQUE [lb-ft]:	93	54	35	0.0
DYNO SPEED [rpm]:	2148	1664	1331	0
DYNO POWER [kW]	28.2	12.8	6.6	0.0
FUEL FLOW [g/hr]:	16247	7341	4451	363
FUEL FLOW [lb/hr]:	37.2	16.8	10.2	0.83
NOx HUMID. ADJ. FACTOR [KH]:	0.834	0.83	0.83	0.83
DRY-WET CONV. FACTOR [K]:	0.887	0.88	0.88	0.88
AIR/FUEL RATIO:	9.2	13.5	14.6	15.3
CO, %[wet]:	9.74	1.75	0.08	0.04
CO2, %[wet]:	7.61	12.14	13.31	12.79
HC, ppmC[wet]:	2000	800	200	200
NOx, ppm[wet]:	38	142	21.9	0.1
O2, %[wet]	0.13	0.11	1.00	0.88
F Factor	1.202	1.202	1.202	1.202
BSFC, g/kW-hr	576	573	678	

WYOMING

Test Number: Wyoming
Engine: 4-Stroke
Rated Speed: 2500 rpm

Date: 3/25/01
Fuel: Premium E10

Time: 04:45 PM
Displacement: 617 cc
Full Throttle Power: 1.48 kW
Weighted Ave. Measured Power: 0.52 kW

Mode	Speed % of Rated	Torque % of Mode 1 Maximum	Mass Emissions, g/hr			Mode Weight Factor	Modal Brake Specific Emissions, g/kWh		
			HC	CO	NOx		HC	CO	NOx
1	100	100	41	1216	24	0.18	28.1	825	16.48
2	85	51	19	55	14	0.39	34.6	100	25.50
3	75	33	54	56	5.2	0.36	541.3	567	53.05
4	IDLE	0	29	693.7	0.9	0.07			

	g/hr		
Weighted Hourly Mass Emissions	36	309	12
	g/kWhr		
Weighted Brake Specific Mass Emissions	70.2	599	22.88

Engine: 4-Stroke **Run #: Wyoming**	**Average Mode 1**	**Average Mode 2**	**Average Mode 3**	**Average Mode 4**
TRACK SPEED [mph]:	41	21	5	0
DYNO TORQUE [lb-ft]:	8	6	5	0.0
DYNO SPEED [rpm]:	1240	635	151	0
DYNO POWER [kW]	1.5	0.6	0.1	0.0
FUEL FLOW [g/hr]:	3968	2689	1962	892
FUEL FLOW [lb/hr]:	9.1	6.2	4.5	2.04
NOx HUMID. ADJ. FACTOR [KH]:	0.853	0.85	0.85	0.85
DRY-WET CONV. FACTOR [K]:	0.884	0.90	0.90	0.88
AIR/FUEL RATIO:	14.1	17.6	18.7	11.1
CO, %[wet]:	2.03	0.11	0.15	6.06
CO2, %[wet]:	11.22	11.05	10.18	9.15
HC, ppmC[wet]:	1400	800	2900	5200
NOx, ppm[wet]:	290	208	100.4	54.0
O2, %[wet]	0.88	2.91	5.37	0.44
F Factor	1.211	1.211	1.211	1.211
BSFC, g/kW-hr	2690	4870	19826	